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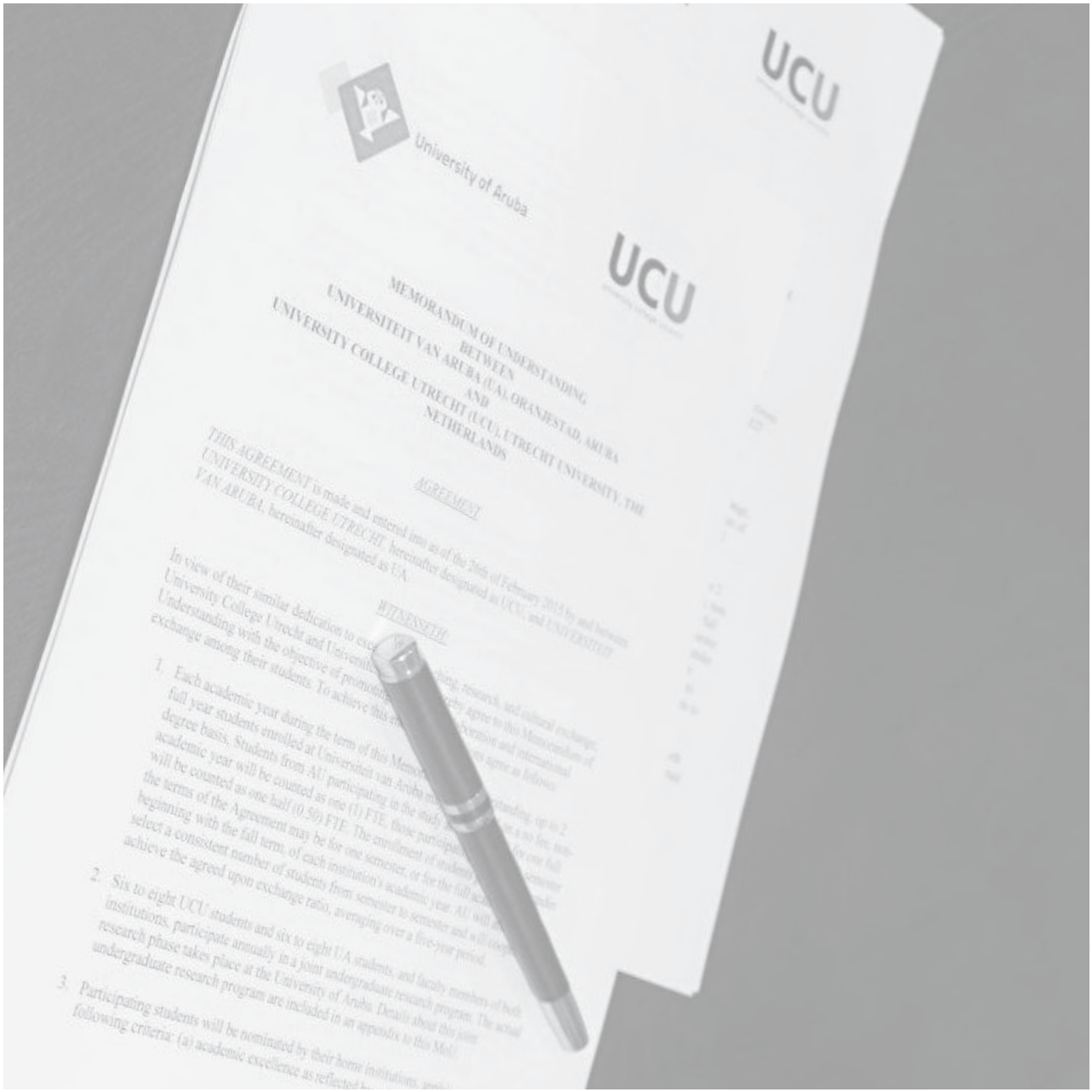
Student Research Exchange *Collected Papers 2025*


University of Aruba
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MEMORANDUM OF UNDERSTANDING
BETWEEN
UNIVERSITEIT VAN ARUBA (UA), ORANJESTAD, ARUBA
AND
UNIVERSITY COLLEGE UTRECHT (UCU), UTRECHT UNIVERSITY, THE NETHERLANDS
AGREEMENT
THIS AGREEMENT is made and entered into as of the 26th of February 2013 by and between UNIVERSITY COLLEGE UTRECHT, hereinafter designated as UCU, and UNIVERSITEIT VAN ARUBA, hereinafter designated as UA.
WITNESSETH:

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Student Research Exchange

Collected Papers 2025


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Student Research Exchange

Collected Papers 2025

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Introduction to the 10th annual volume of the UAUCUU Student Research Exchange Collected Papers

Small island states mirror and magnify the sustainability challenges confronting the world. Aruba is a textbook example of a small island state, one where the community grapples with local and global sustainability challenges, trying to navigate the tricky path between economic development, social cohesion and environmental impacts. Sustainability challenges have become even more pressing, in Aruba and elsewhere, since our first volume was published ten years ago in 2015. This 2025 volume, like previous ones, documents the efforts made by student researchers from the University of Aruba and Utrecht University to address the challenges Aruba faces in meeting the sustainable development goals (SDGs) of the United Nations 2030 agenda. It opens with a list of guiding principles and goals that these students compiled collectively in a UA classroom in February 2025, at the beginning of their 11 weeks together. The ideas in this list express our students' ambitions to do research in ways that would be meaningful to others as well as to themselves. These reflect the principles of community-based research that have been at the heart of our student research collaboration program since it was founded.

In 2025, a total of 17 student researchers completed papers for this publication. They include thesis-year students from the University of Aruba's Sustainable Island Solutions through STEM program and students from University College Utrecht and Global Sustainable Sciences at Utrecht University. The students supported each other's process while working on their own research, morally and practically, providing feedback on approaches to research, and on the content, style, language and structure of the papers submitted for this volume.

The content of this volume includes work grounded in a range of fields: engineering and water management, data sciences, sustainable agriculture, economics, cognitive science, linguistics and history education. The topics include sustainability in food security, renewable energy and resource management, inclusive education and language practices. The research papers appear here as submitted by the authors, including the occasional raw or not yet developed conclusion. Some of the contributions reflect completed studies, others are preparatory explorations, proposals for research that is still to be carried out. All the authors are still working on interpretation and presentation of their findings and will finalize these in consultancy reports or bachelor theses based on the results of the projects presented here. The authors also each wrote a personal reflection about the individual rewards of participating in community-based research, and these preface their papers.

A UA bachelor course (Interdisciplinary and multidisciplinary approaches to sustainable development in small island states) served as a forum for mutual support and collaboration during the process of doing the research, and culminated in presentations of their work to the Aruban community in the newly renovated UA Maria Convent Chapel. Many people have made crucial contributions to the students' success this year. We, and our students, appreciate the value and power of their contributions to this project as a whole. We want to express special gratitude to UA's Esther Plomp, Tobia de Scisciolo, Diego Acevedo and Bart van Donselaar help in providing feedback on the student papers in preparing them for publication here. Many others who have played crucial roles as guides, lecturers, mentors, advisors, facilitators, respondents, interview participants, and engaged citizens: thanks to you all! We hope that you have looked forward to the work that is presented in this volume as eagerly as we did!

Eric Mijts & Jocelyn Ballantyne
Project coordinators UAUCUU

Guiding principles 2025

Realistic
Communicate openly
Stay positive
Feedback
Use each other skills
Reflect often on work done and to be done
Being on time
Understanding positionality
Be engaged and motivated
Respect (show and have)
Support
Kindness & Gentleness
Collaboration
Be aware of biases
Building connections with stakeholders
No plagiarism and other fundamental research ethics

What we need from others

Listening
Respect
Honesty
Empathy
Teamwork
Space/cooperation when needed
Compromising
Ever loving support
Patience
Motivate and engage each other
Give and receive constructive feedback
Clear communication

What we need from lecturers

Enthusiasm
Preparation
Interactive
Interesting slides and information
Advice on research approach
Help with network
Support with data processing
Critical feedback (but constructive), honesty
Open discussions
Flexibility
Clear guidelines/communication of expectations and goals of the project
Creating structure during project to reach goal

Kaja Wilke, Utrecht University

Tired, stressed, and blessed.

Before coming to Aruba, I didn't allow myself any expectations of the island. And I exactly remember the joy and disbelief I felt when my friends — Inger, Gabi, and Sophie — and I went to the beach on our first morning at 7 AM, completely jetlagged and overwhelmed by the fact that we had arrived in paradise. It had rained before, and there was a rainbow over the ocean and palm trees. My time in Aruba, I think, has inspired me a lot to believe in myself more. When Eric gave us his famous island tour, he mentioned how a research paper contributed as main piece of evidence that made the government close the landfill at Parkietenbos. This describes the perspective I developed on the possibilities of my career: what I study and what I do can really change reality. But also that reality is always complex.

Especially how Nathalie, Facundo, Anita, and Eric helped build our network, we even got to interview government officials — it made me get excited for my possible future. But every medal has two sides. I think being so involved with the community in Aruba made me, and I think all of us, want to present really impactful results, and contribute to this place as much as we can. Every day felt like two. Several times I said to Gabi before going to bed: "Do you remember how yesterday…", and she would reply: "Kaja, that happened this morning". Nothing described us better as this: Tired, stressed, and blessed. I for sure learned a lot about myself after that: how much I need my routines, my family, and alone time. I read my motivation letter to apply for the Aruba exchange again, and the first thing I said in it is that I like challenges to grow. And I think this exchange has for sure brought me exactly that. And so much more. So many precious experiences and memories: my mom came to visit, and on her first morning I brought her to the same beach that I saw for the first time. I went sailing on a Hobie Cat with her, snorkeling at Mangel Halto and Tres Trapi,

and it was really special to share it all with her. I celebrated the most amazing birthday here. I adopted a street cat with Gabi, Kibrahacha. My most special experience was getting my diving certificate with PureDiving. I had always wanted to be a mermaid as a little girl, and diving felt exactly like this. It made me feel like a kid again, and I can't wait to dive more in my life now! And the most important thing of this whole exchange was the people: all the amazing farmers I got to interview, who have been more than kind — none of them let us leave without gifts — our teachers, and supervisors, the SISSTEM students, our beloved red car Manuelita, and most of all my passionate team and friends, who drive me crazy and at the same time are the best and funniest people I could have asked for.

The power of framing: How narratives on agriculture shape its implementation on Aruba

Kaja Wilke

1 Introduction

On an island where supermarkets are packed with imported goods and rain is a rare event, what does food security really mean? Global food systems face unprecedented challenges that demand transformative solutions. The High Level Panel of Experts, which is the science-policy interface of the UN Committee on World Food Security emphasizes that "profound transformation is needed to address Agenda 2030 and to achieve food security and nutrition in its four dimensions: availability, access, utilization and stability" (HLPE, 2019). During the the World Food Summit in 1996, food security was defined as:
"Food security exists when all people, at all times, have physical, [social] and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life." (FAO, 1996).

In 2002, the definition was updated to include the word "social" alongside physical and economic access.

The Green Revolution and intensive farming dramatically increased agricultural yields by 150-200% between 1960-2010 (FAO, 2011). However, despite improved productivity, global food security remains elusive with nearly 800 million people undernourished (FAO, IFAD, WFP , 2015). As the global population approaches 9.6 billion by 2050, food systems face growing challenges. But modern agriculture's reliance on intensive practices has led to many other challenges, such as environmental degradation and climate change acceleration, prompting calls for sustainable systems that protect both environmental and public health (Bernard & Lux, 2016).

So, the required transformations must address multiple interconnected challenges, from population growth and urbanization to climate change, biodiversity loss, and natural resource depletion. These challenges are particularly evident in Aruba, with long dry periods and therefore limited water availability (Mijts et al., 2023; Boyer et al., 2020; personal communication with seven farmers, 2025). The island faces additional constraints due to its restricted land area relative to population density—180km2 with 110,000 inhabitants (CBS Aruba, 2024) and fragile ecosystems containing 34 endemic species (Aruba Conservation Foundation, 2025).

1.1 The history of food security

While the concept of food security established at the 1996 World Food Summit remains foundational, different actors promote contrasting approaches to achieving it. The UN Committee on World Food Security (CFS) emphasizes a rights-based approach that considers social, environmental, and economic dimensions of food systems, while the FAO has historically favored a more technical, production-focused perspective (Fouilleux et al., 2017).

This divergence is further complicated by the influence of transnational corporations, particularly agricultural supply companies like Bayer and Corteva, who have become powerful actors in shaping the discourse (Kelloway, 2023). These companies, along with organizations like USAID and the Gates Foundation institutions, often advance market-led approaches focused on increasing productivity through technological innovations, including hybrid seeds, modern farming techniques, and enhanced inputs, such as fertilizers (GRAIN, 2014). Their business models are frequently justified through the narrative of meeting global food demand through technological solutions and increased production.

1.2 Agroecology moving into international conversations on food security

In contrast, agroecology has emerged as an alternative paradigm that challenges this corporate-driven, productivist approach. As highlighted by Fouilleux et al. (2017) agricultural development requires addressing multiple interconnected dimensions simultaneously, rather than focusing solely on production increases. Though agroecology has many definitions, FAO (2018b) has defined it as: "Agroecology is an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems. It seeks to optimize the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system."

The FAO launched major agroecology initiatives starting with a 2014 symposium in Rome, followed by regional seminars worldwide (2015-2017), and a second symposium in 2018. These efforts resulted in the "Scaling up Agroecology Initiatiive" and the formulation of the 10 principles of Agroecology: These include co-creation and sharing of knowledge, synergies, diversity, resilience, efficiency, recycling, responsible governance, human and social values, culture and food traditions, and circular and solidarity economy (FAO, 2018b). In 2017, the CFS requested an analysis of agroecology by the High Level Panel of Experts (HLPE), which resulted in the HLPE report 14: Agroecological and other innovative approaches. It concluded with the following statement: "There is enough evidence that agroecological approaches are able to contribute to transforming food systems, in particular to deliver agriculture that is regenerative in its use of renewable resources and ecosystem services. We need to act now to remove barriers to transitions based on agroecological principles and address lock-ins that make such transitions difficult to achieve."

Also among the scientific community, an increase in research on agroecology can be observed. Nikiema et al. (2023) analyzed the increase of studies on agroecology from 1990 till 2023 in the Web of Science database from 0 to around 200 publications, highlighting the increasing interest by the international scientific community. Galt et al. (2024) found that the growth rate of publications on agroecology is double the growth rate of publications in general.

However, the implementation of these global frameworks at local levels remains challenging, especially given the influence of corporate actors in shaping agricultural narratives and policies. This disconnect calls for a study that investigates the alignment of Aruba's governmental agricultural development approach and UN/FAO frameworks, exploring how agricultural narratives influence policy formation and implementation. And how do these align — or conflict — with global agroecological frameworks as well as the local perspectives of the population and local food producers? The foundations for such a study are presented in this paper.

2 Methods

2.1 Community based research

The overarching approach to the research is based on Strand et al.'s (2003) three community based research (CBR) principles. This means that for this research, firstly, the community of Aruban food producers and consumers made up an active part of the research process, marking the first principle of CBR. The most important part of that were semi-structured interviews with farmers and hobbyist growers, and other relevant stakeholders like governmental organizations and experts, that were conducted for a consultancy report for the Department of Agriculture, Livestock, and Fisheries, Santa Rosa. These interviews focused on perspectives on agriculture in general and they serve as foundational context for this paper. They give an overview of the common narratives about agriculture on Aruba.

A total of 14 interviews were conducted, 7 with soil-based farmers, 4 with innovative farmers, and 3 with organizations involved in decision making.

Next to the semi-structured interviews, visiting farmers markets, talking to farmers there, attending a meeting of the United Farmers Aruba, talking and learning from the Aruban fellow students, and observing the land use while driving through the island provided a different perspective on the community perspective and practices in agriculture. Furthermore, a survey was conducted to gain insights into overall interests of the local population. All three approaches show community involvement, and furthermore underpin the second principle of community-based research, which says that different types of knowledge collection are valid. Thirdly, the goal of CBR should be to achieve social change and justice. The research aimed to create change through its main output—a consultancy report—which was shared with both the community via a symposium and handouts and the government.

2.2 Literature Review

The 14 qualitative interviews, as part of the research on the Aruban perspective on agriculture, were complemented with a search of grey literature like local newspapers, scientific literature, and policy documents specific to Aruba, which will be elaborated in the results section.

Additionally, analysis of UN-related documents, including HLPE, World Bank, and FAO reports, along with scientific literature, helped develop an overview of global perspectives.

Key words for the Google Scholar search included "Agroecology", "Agriculture in the Caribbean", "Feeding the world", "Agroecology and Innovation", "Agriculture in Semi-Arid Climates" , "Agriculture in Small Island States".

2.3 Integrated Food and Employment Survey (IFES)

The last pillar of the methodology are the aforementioned surveys. With a sample size of 50 participants at 5 local supermarkets (Chengs' Supermarket, SuperDoit, Superfood, SaveMore, Hong Kong Supermarket) questions about "perceptions of food security, employment, and cultural engagement with local food production in Aruba" (Integrated Food and Employment Survey, 2025) were asked to voluntary participants. More specifically, the willingness of the population to consume local produce, their preference on the type of food production system, and the factors that drive their consumption patterns (price, quality, nutrition, origin) were investigated.

3 Results

3.1 Perspectives of Aruban stakeholders in positions that inform decision making

Throughout the research process, two people in power positions made clear that they do not see the potential for agroecological food systems to contribute to food security and significant production. Statements such as "they [agroecological farming systems] might be nice and cute but they will not give you the food production, high-level food production" and "I don't think that soil farming on Aruba will ever be of any significance in the totality of food necessity" illustrate that point. Instead, innovative approaches left more of an impression: "For the large scale, for the real food production, you really have to go full innovative way of doing it.", "But the availability of water is a serious issue. That's why I see it happening more in in-house farming with the reusing of water."

As an overall impression, it seems like innovative systems like hydroponics can be understood better as a viable business model and in terms input-output calculations by people in power positions who are not directly involved in agriculture. The variety of agroecological practices on the other hand and the way in which these are implemented make it more difficult for decision makers who are not familiar with the concept to understand the multiple benefits.

On the other hand, another person in a decision-making position saw the potential of agroforestry systems: "We appreciate the approach of forest agriculture. And it's quite fashionable right now. It's a system that produces vegetables and fruits. But the same system, and this is for production, [...] you can use for nature development." At the same time, they questioned the economic and environmental soundness of producing crops that need cooling to survive in Aruba's climate: "You have to condition the room or the area so that they can survive and then produce. It is possible, but it's not wise. It doesn't make economic sense, but also environmentally it doesn't make sense."

The new governmental policy plans for 2025-2028 by the AVP-FUTURO coalition demonstrate, yet again an attitude that is mostly focused on innovative, tech-based solutions. The policy plan shows the governmental perspective: "The Primary Sector Policy is founded on contributing to food security and developing a resilient and robust sector, with the ambition to increase commercial and non-commercial food production in both short and long term, stimulate the use of innovative technology, and implement the necessary conditions that support this transformation." While non-commercial food production could be combined with agroecological approaches, this is not explicitly mentioned, while "innovative technology" is.

Agroecological approaches are hinted at, but are not prioritized or made explicit. The construction of a farmers market in San Nicolas, and the implementation of "information program, knowledge exchange, and implementation of best practices in all schools and neighborhoods" could be interpreted as measures that align with an agroecological principles, such as and co-creation of knowledge and improved access to the local market, but as this is again not explicitly mentioned, it remains unclear what for example is meant with "best practices". As the 34th and 35th out of 39 action points, the first policies that specifically addresses an agroecological aspect read: "Continue with the "Restore and Protect the soil quality", and "Continue with the Food Garden/Agroforestry" project at schools", which refers to educational, non-commercial syntropic gardens at schools across Aruba, that highlight the importance of integrated pest management, recycling of resource, and no chemical inputs, conserving biodiversity.

In conclusion, the plan emphasizes innovation and technology in agriculture through initiatives like an "Agri

Innovation Park" and greenhouse cultivation. Significant investments aim to boost commercial operations, develop infrastructure such as a Farmer's Market, and support education via programs like the Agri Business Academy. While attempts are made to increase the social and environmental sustainability of the primary sector, the focus lies on modern, technology driven and mostly top-down approaches, but minimal evidence can be found that the government wants to support an agroecological food production transformation.

3.2 Perspectives of the local population

In the IFES survey perspectives of the local population on local food production were collected. It is evident that local discourse is more evenly balancing the demand for innovative, in-house approaches to soil-based methods.

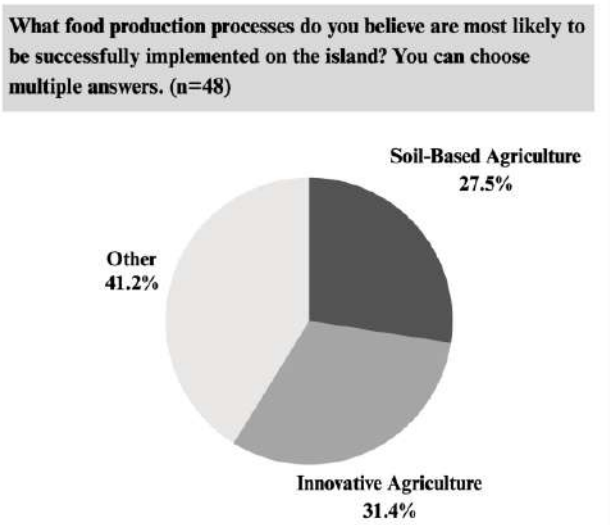

Figure 1 | Answer 9 of IFES survey visualized as a pie chart

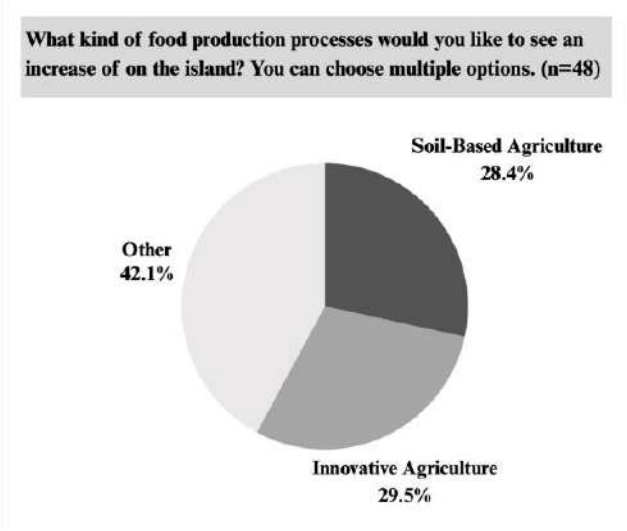

Figure 2 | Answer 10 of IFES survey visualized as a pie chart

Especially the answers of questions 9 and 10 give evidence to this. They show that the local population both sees a potential in scaling up both soil based and innovative agriculture successfully, and also would like to see an increase of both methods evenly.

3.3 Perspectives of local food producers

Just like powerful stakeholders, and the general local population, also the perspectives of food producers are diverse and at different ends of a spectrum. There are hobbyists that produce food in their backyards, driven by passion, and creating beautiful productive oases. One hobbyist said: "And then when you work, even though it's hard work, you forget. And then you feel at ease, calm. And then you hear the birds, and then you hear the bees."

Another hobbyist farmer is using a syntropic approach in their backyard: "I think that the good thing about growing

plants this way is that it is sustainable. It's not like you plant, then you take everything out and you deplete the soil over time, so you need to find a solution for that. It's the other way around. The more you plant, the more you harvest, the more you take care of it, the better the soil will grow."

Figure 3 | Illustration of syntropic backyard garden

Then there are syntropic farms with a focus on soil health, resource efficiency and recycling, diversity, community engagement, and education: "So you try to use different plants to give back things: beans for the nitrogen, bananas for the potassium. That's why you want to have the diversity in your farm so you can get it from the plants themselves", "diversity is key. And having trees in your veggie farms is key as well, because the function of a tree is so much more than providing shade."

Figure 4 | Illustration of educational syntropic farm at a school

Another perspective of agriculture on Aruba is more focused on the economic viability and efficiency of resource use. This includes hydroponics, greenhouses and vertical farming. The goals are targeted towards production of mostly one main cash crop. "We make food for Aruba, basically, if I can say that in a very quick way. We use technology to do that and then we deliver commercially to restaurants, hotels, some supermarkets and we also sell to individuals in Aruba. "

Figure 5 | Illustration of a hydroponic farm

Several overarching themes can be found when analyzing the interviews with farmers. There seems to be a general perception that "real farms" must be large: One farmer said: "Like all the biggest, like the best farms in the world are super huge. They're just super, super huge." Another follows this sentiment, saying: "Maybe it's also difficult for us because we don't consider ourselves farmers because it's small. And I see farmers as being big."

This theme aligns with conventional monoculture agriculture like it is popular in the United States, while UN reports like the HLPE report highlight the need to invest in diverse smallholder agriculture (HLPE, 2019).

3.4 Alignment with UN perspectives

The 2025–2028 Strategic Goals of the Aruban Government and the international documents such as the CFS HLPE report 14 (HLPE, 2019), and the UN "Scaling Up Agroecology Initiative" (FAO, 2018b) share several overarching objectives in strengthening the primary sector and promoting sustainable food systems. Both frameworks acknowledge the urgency of reducing import dependency and increasing local food production to enhance food security. Furthermore, they recognize the importance of sustainable resource use, particularly in water-scarce contexts, and express support for technological innovation and education in agriculture. In this context, Aruba's focus on stimulating youth interest in the sector through educational programs like the syntropic gardens in schools and demonstration sites resonates with the FAO and CFS emphasis on capacity building and knowledge sharing. Protecting and restoring of the soil quality is also one of the aspects that is relevant in CFS and FAO documents.

Despite these points of convergence, significant differences emerge in scope, depth, and framing. While the Aruban government's strategy adopts a pragmatic, project-based approach primarily focused on increasing production and economic viability, the CFS and FAO documents present a more holistic and rights-based framework for food systems transformation. They place strong emphasis on the human right to adequate food and promotes participatory governance mechanisms that engage the civil society. In contrast, Aruba's policies lack explicit reference to rights-based approaches or mechanisms for inclusive governance.

Another notable divergence lies in the conceptualization of sustainability. The Aruban strategy, while incorporating elements of water efficiency and solar energy, does not explicitly reference agroecology or the FAO's 13 principles for sustainable food systems (FAO, 2018a; FAO, 2018b). The FAO and CFS approach views agroecology not merely as a set of practices, but as a paradigm shift encompassing ecological, social, and cultural dimensions. Moreover, critical areas such as food loss and waste reduction, climate resilience, and "applying ecological principles to agriculture and ensuring a regenerative use of natural resources and ecosystem services" are largely absent from Aruba's strategic vision. The UN documents explicitly address these dimensions, emphasizing ecosystem restoration.

These differences highlight the potential for Aruba to enhance its agricultural strategy by adopting more integrative and transformative approaches aligned with global frameworks. Incorporating principles from the CFS and FAO guidelines could enable a broader systems perspective that goes beyond production and economic outcomes to encompass food justice, environmental stewardship, and community resilience.

4 How does it all fit together?

4.1 The Power of Discourse in Shaping Policy and Perception

As Fouilleux et al. (2017) argue, framing matters: the way food security is defined determines the types of solutions that are deemed valid, fundable, or worth pursuing. These discourses do not simply inform policy—they actively shape how policymakers and communities conceptualize agriculture itself. In Aruba, policy documents such as the 2025–2028 national strategy reflect an interpretation of food security influenced by international productivist narratives. Emphasis is placed on controlled-environment agriculture, greenhouse development, and high-tech solutions as pathways to resilience and economic viability.

While these approaches are not inherently problematic, the discourse that surrounds them, callend the "innovation frame" by Anderson and Maughan (2021), often overshadows the transformative and holistic

nature of agroecological farming systems and principles. This alignment with a narrow version of innovation corresponds with the "productivist" paradigm described in the literature, where food security is primarily understood in terms of yield and market integration (Fouilleux et al., 2017; Altieri, 1989). However, this paradigm risks excluding solutions better aligned with Aruba's unique ecological constraints and social landscape. Importantly, it obscures the full range of contributions that small-scale, diverse, and community-oriented food producers make to the island's food system.

4.2 Understanding Food Security as a Multi-Dimensional Concept

Food security, as defined by the FAO and HLPE, extends beyond the production of food. It consists of four essential dimensions: availability, access, utilization, and stability (FAO, 1996; HLPE, 2017). Availability refers to the presence of sufficient quantities of food through domestic production or imports. Access involves individuals' ability to acquire food physically and economically. Utilization encompasses food safety, nutrition, and cultural appropriateness, while stability refers to the consistent and reliable provision of these dimensions over time and during crises.

These dimensions must be understood alongside the three pillars of sustainability: environmental, social, and economic, which underpin the long-term viability of any food system (HLPE, 2019). A farming model that produces high yields but undermines soil health, water availability, or farmer livelihoods cannot be considered secure in the long run. Conversely, a model that fosters biodiversity, community engagement, and knowledge-sharing — even if it operates at a smaller scale — can play a vital role in strengthening the local food system. To better understand the environmental dimension of the food system sustainability, the concept of ecosystem servicescan be taken as an example. Depending on the farming methods employed, each of these ecosystem services in relation to the farm could be leveraged or undermined:

- **Carbon Sequestration:** Carbon can be stored in biomass, especially trees, and in soils.
- **Water Efficiency:** Soils depending on their management can be efficient at taking up rainwater instead of runoff.
- **Climate Regulation:** Vegetation helps regulate temperature and carbon.
- **Nutrient Cycling:** Native plants and microbes recycle nutrients, reducing the need for external inputs.
- **Soil & Land Habitats:** Soils support microbes and insects vital for fertility, while crops can give habitat for land animals such as birds.
- **Flood Regulation:** Vegetation slows runoff during heavy rains.
- **Food, Fibre & Fuel:** Local crops provide food, medicine and building materials..
- **Cultural Traditions:** Farming ties to heritage and identity.
- **Land Habitats:** Dry forests support native birds, reptiles, and insects.
- **Pollination:** Insects support crops and wild plants.
- **Air Purification:** Vegetation modestly improves air quality.
- **Cooling:** Trees provide shade and reduce heat.

The findings of this study suggest that many Aruban farmers are already contributing to these broader dimensions. Soil-based syntropic systems regenerate ecosystems while cultivating community relationships and food traditions. Hydroponic systems increase availability and provide economic opportunities. Backyard farmers enhance access and utilization of food by sharing produce within families and neighborhoods. All of these approaches contribute to food security in ways that are often not captured by mainstream policy frameworks focused solely on productivity.

4.3 Beyond Binary Thinking: Recognizing Complementarity and Local Innovation

Despite the contrast between high-tech and agroecological systems in policy discourse, the lived realities of farmers in Aruba show that these models do not exist in isolation or opposition. Rather, farmers are navigating a complex landscape, experimenting with mixed systems, and adapting practices based on their specific contexts. Some are trying to integrate agroecological principles into hydroponic setups, while others are learning about scaling up soil-based production through composting and water-saving techniques. There is no single "right" way to farm on the island.

This diversity is a strength. As the FAO (2018) emphasizes, agroecology is not a fixed model but a flexible, evolving framework grounded in place-based knowledge, co-creation, and adaptive governance. What works in one region or for one farmer may not work for another. Recognizing this diversity and avoiding prescriptive approaches is essential for building resilient food systems in ecologically vulnerable and socially diverse contexts such as Aruba.

The idea that small farmers are not "real" farmers unless they scale up or commercialize was echoed in several interviews. This internalization of productivist norms speaks to the deep influence of discourse on identity. Yet, the agroecological literature challenges these assumptions, arguing that legitimacy in agriculture should not be measured by size or market reach alone, but also by contributions to biodiversity, social cohesion, food access, and environmental stewardship (Altieri, 1989; HLPE, 2019).

4.4 Building Food Security Through Community and Relational Infrastructure

A key insight emerging from this research is the importance of relationships — in knowledge, labor, and trust — in supporting sustainable food systems. The term "relational infrastructure" is used in the literature to describe the social, institutional, and educational systems that enable diverse actors to work together, exchange knowledge, and build collective resilience (HLPE, 2019). In the Aruban context, this includes everything from farmer cooperatives and informal mentorship networks to community gardening events and school-based agroforestry programs.

When farmers talk about their gardens as places of peace, healing, and shared abundance, they reveal that agriculture is not only a technical or economic activity but a social and cultural practice. These experiences strengthen community identity and foster intergenerational knowledge transfer, elements that are vital to sustainable food systems but are often undervalued in policy frameworks.

Policy interventions that focus exclusively on infrastructure and technology miss these crucial human dimensions. Investment in relational infrastructure, such as knowledge hubs, peer-to-peer learning programs, or participatory planning platforms, can amplify the impact of technical innovations by embedding them in community-centered processes. This, in turn, creates food systems that are not only more resilient but also more just.

4.5 Knowledge, Legitimacy, and the Politics of Innovation

The final issue this discussion highlights is the role of knowledge in determining which agricultural practices are considered valid, modern, or forward-looking. As Altieri (1989) and the HLPE (2019) emphasize, transformation requires the redistribution of epistemic power. Farmers must not only be recipients of scientific knowledge but recognized as co-producers of it.

In Aruba, where multiple generations of food producers, educators, and innovators already experiment with

techniques adapted to arid climates and limited resources, there is an opportunity to strengthen community-based research and policy co-creation. The interviews and fieldwork for this study revealed that many actors across the agricultural spectrum are eager to collaborate and learn from one another. What is missing is not willingness, but institutional mechanisms that support inclusive, cross-sector dialogue and mutual recognition.

By reframing innovation to include agroecological adaptation, intergenerational knowledge-sharing, and low-tech problem-solving, policymakers can broaden the scope of what is seen as valuable and possible. This reframing is essential for aligning agricultural development with both local realities and the multi-dimensional goals of food security.

References

- Altieri, M. A. (1989). Agroecology: A new research and development paradigm for world agriculture. Agriculture, Ecosystems & Environment, 27(1-4), 37–46. https://doi.org/10.1016/0167-8809(89)90070-4
- Anderson, C. R., & Maughan, C. (2021). "The Innovation Imperative": The Struggle Over Agroecology in the International Food Policy Arena. Frontiers in Sustainable Food Systems, 5. https://doi.org/10.3389/fsufs.2021.619185
- Aruba Conservation Foundation. (2025). Aruba Conservation Foundation . Acf.aw. https://acf.aw
- Bernard, B., & Lux, A. (2016). How to feed the world sustainably: an overview of the discourse on agroecology and sustainable intensification. Regional Environmental Change, 17(5), 1279–1290. https://doi.org/10.1007/s10113-016-1027-y
- Boyer, M., Horton, J., & Millán, M. F. (2020). "Building Resilience in Aruba's Food Security During the COVID-19 Pandemic and Beyond." World Bank. Grosjean Christophe Frederic Robert, Arias Ramón Ernesto, Lopez Elena Mora, Wrede Peter, de Kort Rendell Ernest, Justiniano Ivelisse, and Chapman Regis.
- CBS. (2023). The development of the population of Aruba. https://cbs.aw/wp/index.php/2022/11/24/test-births/
- FAO. (1996). The State of Food and Agriculture. Fao.org. https://www.fao.org/4/w1358e/w1358e14.htm#P0_0
- FAO. (2011). Save and grow—a policymaker's guide to the sustainable intensification of smallholder crop production. United Nations, Rome.
- FAO. (2018a). Agroecology: from advocacy to action. https://www.fao.org/fileadmin/user_upload/bodies/COAG_Sessions/COAG_26/MX456_5/MX456_COAG_2018_5_en.pdf
- FAO. (2018b). Scaling up Agroecology Initiative.

https://openknowledge.fao.org/server/api/core/bitstreams/a21f0e9e-7cc4-4975-ad0a-36aac7a35cfb/content

- FAO, IFAD, WFP . (2015). State of food insecurity in the world. FAO, Rome.
- FAO's Work on Agroecology | Agroecology Knowledge Hub | Food and Agriculture Organization of the United Nations. (n.d.). Www.fao.org. https://www.fao.org/agroecology/overview/our-work/en/
- Fouilleux, E., Bricas, N., & Alpha, A. (2017). "Feeding 9 billion people": global food security debates and the productionist trap. Journal of European Public Policy. https://doi.org/10.1080/13501763.2017.1334084
- Galt, R. E., Pinzón, N., Nicholas Ian Robinson, & Beatriz, M. (2024). Agroecology and the social sciences: A half-century systematic review. Agricultural Systems, 216, 103881–103881. https://doi.org/10.1016/j.agsy.2024.103881
- GRAIN. (2014). How does the Gates Foundation spend its money to feed the world? Grain.org. https://grain.org/e/5064
- HLPE. (2019). Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
- Integrated Food and Employment Survey (E. Bouchired, K. Wilke, S. Sophie, G. Lopez Valle, I. M. B. Rødnes, K. Kyriakidou, & P. D. Hesseling, Interviewers). (2025). In Google forms. https://docs.google.com/forms/d/e/1FAIpQLScTu0fGmHkRoYqz60K_b-P7Mp7vuFv8wVKM-KN55ZtP1tTHGA/viewform. [Unpublished raw data].
- Kelloway, C. (2023). USDA Report Highlights Harms of Seed Consolidation and Restrictive IP. Food & Power. https://www.foodandpower.net/latest/usda-seeds-report-3-23
- McKeon, N. (2016). Civil Society-Public Institution Relations in Global Food Policy: The Case of FAO and the CFS. Partnerships in International Policy-Making, 71–88. https://doi.org/10.1057/978-1-349-94938-0_4
- Mijts, E., Singh, S., & Martin del Campo, F. (2023). The resource (in)su ciency of the Caribbean: analyzing socio-metabolic risks (SMR) of water, energy, and food. Frontiers. Clim. 5:1085740. doi: 10.3389/fclim.2023.1085740.
- Nikiema, T., Ezin, E. C., & Kpenavoun Chogou, S. (2023). Bibliometric Analysis of the State of Research on Agroecology Adoption and Methods Used for Its Assessment. Sustainability, 15(21), 15616. https://doi.org/10.3390/su152115616
- Olson, J. (2011). Understanding and contextualizing social impacts from the privatization of fisheries: An overview. Ocean & Coastal Management, 54(5), 353–363. https://doi.org/10.1016/j.ocecoaman.2011.02.002
- Schroeder, P. (1994). Carbon storage benefits of agroforestry systems. Agroforestry Systems, 27(1), 89–97. https://doi.org/10.1007/bf00704837
- Strand, K. J., Cutforth, N., Stoecker, R., Marullo, S., & Donohue, P. (2003). Community-based research and higher education: Principles and Practices. John Wiley & Sons, Incorporated.

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Don't be a headless chicken.

I applied to the Aruba program in the hopes that this experience would allow me to gain a new perspective in life. Growing up in western Europe, I felt stuck in my vision on the world and global issues. I am now happy to report that this adventure has taught me everything I hoped for and more. From the time spend in class learning various issues on the Caribbean life, to time used exploring the beauty and complexity of the island, and finally to meeting new people from the community and from other countries. I have learned that there is truly no better way to grow as an individual than to put yourself out there with an open mind. Being able to achieve all of this with a close friend of mine also reminded me on the importance of the presence of the people we share life with, and get to reflect on our journey together.

Conducting the Consultancy Project on Aruba would have been absolutely impossible without the help and contribution of so many people we have met. I want to thank all the teachers that have given us valuable insights on the island life and grounding us in the harsh and true reality of it, as well as guiding us through this program. To all the people who offered their time to us, from the ones who kindly participated to our surveys on their way to the supermarket, to the ones who offered their times for our interviews and always offered a warm welcome. I learned from their generosity and kindness, as well as from their knowledge on agriculture and food security on the island. I will leave this island full of new metaphors on life, which I have gathered from the interviewees, with my most favourite: "Don't be a headless chicken".

But finally, I want to extend my thanks to my incredible team of seven other people who made it all possible. We all arrived a bit lost on how we were going to overcome this challenge, with all of us having different strengths and ideas

on how to conduct this project, which revealed itself to be more challenging than we expected. But this was without counting on all the resources and perseverance everyone had in proving we were capable of it. They knew how to make hard times more enjoyable, stressful times more bearable, and most importantly, how to make fun times even more memorable. I genuinely cannot express how grateful I am to have been able to learn from each of these people who are so unique in their own way, both as students and as people. To the One Happy Team, thank you so much for making this time one happy journey :)

Sustainable Land Use Planning: How Syntropic Farming contributes to Soil and Ecosystem conservation in Aruba

Enza Bouchired

1. Introduction

1.1. Context of Aruba and Its Natural Environment

Aruba is a Tropical Small Developing Island State (SDIS) with a semi-arid, hot climate (Ridderstaat et al., 2014). The island is environmentally and economically challenged, primarily explained by its rapid urbanization induced by tourism, which is its main economic activity (De Kort et al., 2023). Urban expansion has intensified competition for space and resources, where sustainable land use planning should be considered. The principal challenges for land use planning, both in Aruba and the Caribbean islands, have been limited agricultural land (Jurgens et al., 2024), water scarcity, and soil degradation (Hurni, 1997). As a result, sustainable land use planning becomes necessary to consider to balance the protection of the environment, economic needs, and social development.

1.2. Food Security and Agriculture

Currently, the island has a drastic difference in its quantity of imported and local food. Indeed, imports are around $157 million USD of food, in comparison to $1.2 million USD for local food production (Boyer et al., 2022; Wolfs Company et al., 2018). After the COVID-19 pandemic, it became clearer than ever that Aruba's reliance on exports made it vulnerable to global market fluctuations and supply chain disruptions (De Jong et al., 2023). This explains the desire for the island to increase its local food production. However, because of Aruba's climate, the island is not desirable for large-area agricultural pursuits (Schmutz et al., 2017). Indeed, due to its semi-arid climate and limited natural resources, Aruba's agricultural sector is limited by a number of factors. First, water scarcity limits agricultural potential further, as Aruba depends on costly desalination processes and has very limited groundwater resources (Boyer et al., 2020). Then, climate change exacerbates drought and accelerates soil erosion, making it even more difficult for conventional farming practices to succeed. While government policy acknowledges the significance of sustainable land use, they prefer economic development to ecological sustainability and hence result in disarticulated conservation and low investment in agriculture research (De Kort et al., 2023).

1.3. Syntropic Farming Relevance

Syntropic agriculture, a regenerative form of agriculture, is a viable solution to land use and environmental concerns in Aruba. Syntropic agriculture is a regenerative form of agriculture that enhances soil quality, reduces chemical pollution, and increases biodiversity (Kettley, 2024). Given the vulnerable environment of Aruba, the integration of syntropic agriculture into land use is likely to increase environmental sustainability and food security,. Syntropic

farming is also in line with international sustainability targets, with a climate-resilient option that is particularly suitable for island nations facing unpredictable weather patterns and environmental risk (Son et al., 2023).

1.4. Research Question

This paper addresses the potential role of syntropic farming in fostering sustainable land use planning in Aruba, namely soil preservation and ecosystem health. The overarching research question that will guide this discussion and conclusion is:

How can syntropic farming contribute to soil health and ecosystem conservation in Aruba's semi-arid environment?

This paper argues that integrating syntropic agriculture with sustainable land management can provide a more stable and environmentally sustainable agricultural industry in Aruba. By working towards reducing soil erosion, land resource limitations, and urbanisation stresses, sustainable farming can help develop a more stable and environmentally conscious food system in the island.

2. Methods

In order to answer the research question of this paper, the result section will be divided into two parts: literature review and interviews findings.

The literature review will be used for several purposes. Firstly, it will be used to define the relevant terms for this paper, secondly to assess and determine the current state of soil and ecosystem conservation in Aruba, and finally to evaluate the benefits of syntropic farming for soil health and ecosystem conservation.

Following this, a Community-Based Research (CBR) approach will be integrated to this paper to ensure that local stakeholders perspectives on syntropic farming will be considered when discussing the potential of syntropic farming on Aruba (Luger et al., 2020). The interviews were conducted through a snowball sampling, where stakeholders have referred to other relevant participants for the research. Furthermore, they were realised in the form of semi-structured interviews to allow for a more open dialogue (Newcomer et al., 2015). It is important to note that due to the lack of syntropic farmers on the island, the stakeholders chosen are not necessarily working full time as such, but either farmers who undertake similar basic practices to syntropic farming, or hobbyists who do not pursue their practice to the commercial level. A total of 6 stakeholders were interviewed, all defined as: I1, I2, I3, I4, I5 and I6. Their knowledge will be applied to this paper in order to assess the impacts of syntropic agriculture on soil health and biodiversity in the context of Aruba.

The answers from the interviews were then coded through the platform NVivo and divided into the following criteria:

- Soil/Water
- Biodiversity
- Input enhancers

These criteria were chosen based on the main ecosystem services that can be provided from a syntropic farm. This includes soil for soil erosion, and water for soil capacity of water retention. Input enhancers are relevant for this paper since it consists of natural and synthetic products used in an agricultural context, with the latter capable of degrading the soil quality.

Questions during the interviews include: Does your farm contribute to flood erosion?/Does your farm contribute to erosion control and nutrient cycling?/Does your farm support other species other than the crops you grow?/What other appliances do you need for production?

3. Results

3.1. Literature review findings

3.1.1. Sustainable Land use planning, agriculture and conservation

Sustainable land use planning aims to maintain ecological balance while supporting economic development. It plays a crucial role in preventing deforestation, protecting biodiversity, and promoting sustainable farming (van Lier et al., 2002). Therefore, well-planned land use would ensure that agricultural activities do not lead to environmental degradation, allowing for the coexistence of farming and conservation efforts. A combination of strong land use policies and incentives for sustainable farming can ensure that agricultural development does not come at the cost of environmental degradation (Lambin et al., 2014). In Aruba, applying such principles can help balance the need for food production with ecological preservation.

Examining case studies from other small island nations provides valuable insights for Aruba. For example, the Azores have successfully integrated syntropic farming with conservation programs, preserving soil quality and biodiversity with Green Space Management (Zampolini, 2023). This case study highlights the importance of government support, public awareness, and adaptive policies in achieving sustainable land use. Lessons learned include the need for financial incentives for syntropic farmers, investments in water-efficient agricultural technologies, and community participation in land management decisions. Furthermore, the Pacific island nation of Fiji has adopted agroforestry techniques that integrate trees and crops, which ended up improving soil health (Prasad, 2014). Both of these strategies provide models for Aruba to develop land use policies that sustain both agricultural and conservation goals.

3.1.2. Syntropic farming, soil health and ecosystem restoration

Syntropic farming is a type of regenerative agriculture which consists of multiple practices that aim to recreate nature by diversifying the plants that grow together (Andrade & Pasini, 2022). This method enhances soil health (Kettley, 2024) by improving fertility, and microbial diversity (Ortega et al., 2024). Conventional farming methods often prioritize short-term yields over long-term sustainability, leading to environmental harm (Mozumder & Berrens, 2007). Syntropic farming, by contrast, relies on natural fertilizers, crop rotation, and biological pest control to maintain soil and plant health. Studies have shown that syntropic farms have healthier soil microbiomes, lower levels of chemical residues, and improved ecosystem functions (Vaupel et al., 2025). As this practice puts emphasis on natural input enhancers such as compost, manure, and cover crops. Research shows that by doing so, syntropic farming increases soil organic matter, improves water retention, and fosters beneficial microorganisms (Jaysawal et al., 2023). Moreover, syntropic farming plays a vital role in restoring degraded lands and conserving biodiversity (Miatton et al., 2020). By avoiding harmful chemicals and adopting regenerative practices, syntropic farmers enhance soil health, promote pollinator populations, and support native plant species (Kettley, 2024). On the other hand, the use of synthetic fertilizers and pesticides contributes to soil degradation, water contamination, and loss of biodiversity. Transitioning to syntropic farming in Aruba could mitigate the negative effects of chemical dependency and contribute to a healthier environment.

Furthermore, poor soil structure and low organic matter can lead to erosion, nutrient loss, and reduced water absorption (Horn et al., 1995). Syntropic farming techniques, such as minimal tillage and crop rotation, address these issues by preserving soil quality (Jaysawal et al., 2023). In Aruba's context, where soil quality is already compromised by arid

conditions, syntropic methods could play a crucial role in restoring soil productivity. Furthermore, when comparing traditional farming methods with syntropic practices reveals that syntropic systems are more resilient to extreme weather conditions such as hot summers (Kettley, 2024).

3.2. Interview Findings

Soil/Water Findings	Prevalence	Interview
Undertake crop rotation	100%	I1, I2, I3, I4, I5, I6
Undertake composting for soil health	100%	I1, I2, I3, I4, I5, I6
Describe their soil with no erosion	66.7%	I1, I3, I5, I6
Describe their soil as water absorbent	83.3%	I1, I2, I3, I5, I6
Describe their soil as healthy/rich	83.3%	I1, I2, I3, I4, I5,

Table 1: Soil and Water Findings

All the farmers interviewed (100%) undertake the practice of composting and rotation of crops, reflecting on the importance of commitment to soil fertility and health. Indeed, an interviewee stated that "The more you plant, the more you harvest, the more you take care of it, the better the soil will grow." (I3, personal communication, 2025). The majority (83.3%) described their soil as water absorbent from precipitations, which reflects that their farming methods are more water-retentive, and that the soil is rich enough to absorb all the water. Additionally, 83.3% described their soil as healthy and fertile, confirming the benefit of their soil management systems. However, only 66.7% had no sign of erosion, suggesting that some of the farmers are still experiencing soil erosion on their farms.

Biodiversity Findings	Prevalence	Interview
Describe their farm as supporting other species than the plants they grow	100%	I1, I2, I3, I4, I5, I6

Table 2: Biodiversity Findings

All the farmers interviewed (100%) confirmed that their farm had plant species beyond the crops they produced. Additionally, other species are also supported such as a farmer stated "We have a beehive, Birds. In the morning we hear them. And this one also. Sometimes there will be an iguana in here. A lot of butterflies. A lot of butterflies." (I4, personal communication, 2025). This supports the fact that biodiversity conservation was a shared priority among the interviewees either through natural environments, pollinator agriculture, or agroforestry elements. Furthermore, an interviewee showed the importance of including biodiversity since "last year, there was a corner where we had multiple different plants. And we even grew bok choy, which I never thought we could grow in this soil. But that was a combination of bok choy, cucumber, zucchini, corn, and beans. So when we put them together, somehow they grew." (I4, personal communication, 2025). This demonstrates the benefits of a land that hosts vast biodiversity can have on soil and food production.

Input Enhancers Findings	Prevalence	Interview
Uses natural input enhancers	100%	I1, I2, I3, I4, I5, I6
Uses synthetic input enhancers	50%	I1, I4, I5

Table 3: Input Enhancers Findings

All farmers (100%) use natural input enhancers, indicative of a preference for organic soil amendments or bio-based fertilizers. As noted from one interviewee, they do so "because synthetic fertilizers are killing the land. It gives to the plant, but the land stays dry." (I1, personal communication, 2025). However, 50% of the respondents also use synthetic input enhancers, indicating that some continue to use conventional agricultural inputs alongside natural means. Indeed, the same farmer explained that even though protecting nature is important to them, during the producing season they "try to avoid using synthetic. But if you need thicker, then you have to…" (I1, personal communication, 2025).

4. Discussion

The findings confirm the strength of sustainable agriculture practices on soil health and ecosystem restoration. The practice of crop rotation (100%) and composting (100%) demonstrates that farmers recognize soil fertility and the preservation of organic matter. This is attested to by existing literature on sustainable land use planning, which contends that soil health is imperative in ensuring long-term agricultural productivity. However, the fact that only 66.7% of the farmers reported that they had no soil erosion means that there still remains some land degradation issue in some farms and it could be explained by factors such as water supply, land management or vulnerability to extreme weather conditions.

Then, water retention is also a major determinant of soil sustainability in arid regions. The majority of the farmers (83.3%) reported that their soil is water-retentive, suggesting that their soil management operations effectively enhance water-holding capacity. These findings aligns with the research on syntropic farming where water conservation and soil regeneration are achieved through the use of organic enhancers. The literature also supports this by adding on this topic through to the fact that syntropic methods increase microbial diversity, which contributes to soil water-holding capacity and structure, an essential element in agriculture under Aruba's dry climate.

Following this, conservation of biodiversity and ecosystems was also a principal concern of the study, and all farmers (100%) claimed that their farms support species alongside the crops that they grow. This promotes agroecology and conservation agriculture, which is concerned with reconnecting agriculture to ecosystem restoration. The presence of several species, including native ones such as the Shoco, means that the interviewed farmers are preserving habitat diversity, either through agroforestry, pollinator habitats, or reducing chemical applications. With regards to the latter, all the farmers responded that they use natural inputs, for instance, manures or compost, which is in line with syntropic practices of reducing chemical dependency. However, 50% of the farmers also responded that they use synthetic input enhancers, showing only partial adoption of traditional inputs in agriculture. While this does not negate their dedication to sustainability, it shows that complete conversion to organic farming can still remain a concern.

Finally, it is important to highlight the limitations of the research process for this paper. Collecting data was realised in the span of two months, and only done on a limited amount of stakeholders which were six. As a result, no data was collected on the quality of the soil on the farms, the presence of biodiversity in the interviewed farms, or comparison between soil where chemical fertilizers were used compared to one who only made use of compost. This remains an important limitation on which future research could add on to further assess syntropic farming on Aruba. Furthermore, literature on syntropic farming in an environment similar to Aruba is limited, which means further research should be done to assess in more depth how Aruba could apply syntropic farming correctly in its climate.

5. Conclusion

To conclude, this study highlights the potential for maintains syntropic agriculture's position as another means for boosting soil sustainability and preserving Aruba's ecosystem. Syntropic farming has a lot of potential to contribute to soil health and ecosystem conservation inon Aruba's semi-arid environment. Indeed, crop rotation, composting, and natural inputs utilization, a lot of which farmers are doing currently, demonstrate that farming can be resilient with the soil. Literature review highlights the success of syntropic farming and sustainable land use planning in island countries, and they demonstrate that well-integrated and a policy can provide rich benefits to

agriculture and the environment. Furthermore, the research summarised in this paper can be used as a backbone for future research which could expand further on this topic. For example, research will have to explore the long-term effects of syntropic farming on Aruban soil quality, such as how different approaches impact moisture retention, microbial populations, or even carbon sequestration. Moreover, quantifying economic obstacles to reducing synthetic inputs might provide insights into incentives for encouraging farmers to transition more fully to sustainable methods. Overall, this study contributes to the existing knowledge in support of regenerative agriculture as a solution for food security and environmental conservation in semi-arid environments.

References

- Andrade, D., & Pasini, F. (2022). What is syntropic farming? https://terrasintropica.com/wp-content/uploads/2022/10/Syntropic_Farming_Wikifarmer_April_2022.pdf
- Boyer, M., Horton, J., Millán, M. F., Grosjean, C. F. R., Arias Ramón, E., Lopez, E. M., Wrede, P., de Kort, R. E., Justiniano, I., & Chapman, R. (2020). "Building Resilience in Aruba's Food Security During the COVID-19 Pandemic and Beyond." World Bank. https://documents1.worldbank.org/curated/en/099055001092318003/pdf/P17123716194860f019da61c5389ccf3a89.pdf
- De Jong, R., Hoogstad, E., Visser, B., de Kort, R., Carmona Baez, A., Echteld, E., & Mijts, E. (2023). Being prepared for exogenous shocks: Exploring strategies to transform the food system of Curaçao, Aruba and Sint Maarten. In R. S. Severing, E. Echteld, W. Rutgers, & S. Delgado (Eds.), Southern Entanglements: Southern Epistemologies, Southern Praxes and The Languages, Literatures and Cultures of the Dutch Caribbean and Beyond (pp. 13-28). University of Curaçao/University of Puerto Rico.
- De Kort, R., De Jong, R., Hoogstad, E., Carmona Báez, A., Echteld, E., & Mijts, E. (n.d.). Exploring amplified Food Security vulnerabilities in Curacao, Aruba and Sint Maarten amidst the COVID-19 pandemic Island Innovation Policy Brief. https://islandinnovation.co/wp-content/uploads/Policy-Paper-Exploring-amplified-Food-Security-vulnerabilities-in-Curacao-Aruba-and-Sint-Maarten-amidst-the-COVID-19-pandemic.pdf
- Horn, R., Domżżał, H., Słowińska-Jurkiewicz, A., & van Ouwerkerk, C. (1995). Soil compaction processes and their effects on the structure of arable soils and the environment. Soil and Tillage Research, 35(1-2), 23–36. https://doi.org/10.1016/0167-1987(95)00479-c
- Hurni, H. (1997). Concepts of sustainable land

management. ITC journal, 210-215.

- Hurni, H. (2000). Assessing sustainable land management (SLM). Agriculture, Ecosystems & Environment, 81(2), 83–92. https://doi.org/10.1016/s0167-8809(00)00182-1
- Jaysawal, P.K., Tirkey, N., Yadav, R. S., Singh, S., & Prasad, S.M. (2023). Natural Farming. Modern Agronomy-Theory and Practices, 331.
- Jurgens, S. S., Mijts, E., & Anton Van Rompaey. (2024). Are there limits to growth of tourism on the Caribbean islands? Case-study Aruba. Frontiers in Sustainable Tourism, 3. https://doi.org/10.3389/frsut.2024.1292383
- Kettley, A. (2024). What soil is worth: A cost-benefit framework analysis of syntropic farming. SIT Digital Collections. https://digitalcollections.sit.edu/isp_collection/3772/
- Lambin, E. F., Meyfroidt, P., Rueda, X., Blackman, A., Börner, J., Cerutti, P. O., Dietsch, T., Jungmann, L., Lamarque, P., Lister, J., Walker, N. F., & Wunder, S. (2014). Effectiveness and synergies of policy instruments for land use governance in tropical regions. Global Environmental Change, 28, 129–140. https://doi.org/10.1016/j.gloenvcha.2014.06.007
- Luger, T.M., Hamilton, A.B., & True, G. (2020). Measuring Community-Engaged Research Contexts, Processes, and Outcomes: A Mapping Review. The Milbank Quarterly, 98(2), 493–553. https://doi.org/10.1111/1468-0009.12458
- Modern Agronomy - Theory and Practices. (2023). Google Books. https://books.google.com/books?hl=en&lr=&id=zas8EQAAQBAJ&oi=fnd&pg=PA331&dq=syntropic+farming+compost&ots=De7TyV-Xod&sig=l00yEG87wnSih5rfQ4whbkGEDNg#v=onepage&q&f=false
- Miatton, M., & Karner, M. (2020). Regenerative Agriculture in Latin America. Mustardseed Trust Research Reports.
- Mozumder, P., & Berrens, R. P. (2007). Inorganic fertilizer use and biodiversity risk: An empirical investigation. Ecological Economics, 62(3-4), 538–543. https://doi.org/10.1016/j.ecolecon.2006.07.016
- Newcomer, K. E., Hatry, H. P., & Wholey, J. S. (2015). Handbook of Practical Program Evaluation (4th ed., pp. 492–505). Jossey-Bass, A Wiley Imprint.
- Ortega, R., Miralles, I., Domene, M. A., Meca, D., & del Moral, F. (2024). Ecological practices increase soil fertility and microbial diversity under intensive farming. Science of the Total Environment, 954, 176777. https://doi.org/10.1016/j.scitotenv.2024.176777
- Prasad, V. (2014). Adopting agroforestry for improved soil health in the Pacific. In XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1129 (pp. 35-40). https://doi.org/10.17660/ActaHortic.2016.1129.5
- Ridderstaat, J., Oduber, M., Croes, R., Nijkamp, P., & Martens, P. (2014). Impacts of seasonal patterns of climate on recurrent fluctuations in tourism demand: Evidence from Aruba. Tourism Management, 41, 245–256. https://doi.org/10.1016/j.tourman.2013.09.005
- Schmutz, P. P., Potter, A. E., & Arnold Modlin, E. (2017). Aruba, Bonaire, and Curaçao. World Geomorphological Landscapes, 293–317. https://doi.org/10.1007/978-3-319-55787-8_18
- Son, H., Bui, T., & Tuan. (2023). Promoting nature-based solutions for climate resilience and low carbon economy among ethnic minorities: A case study of Son La province, Vietnam. https://www.apn-gcr.org/wp-content/uploads/2023/10/Promoting-NbS-for-climate-change-resilience_Ho-Son.pdf
- van Lier, H., & De Wrachien, D. (2002). Land use planning: A key to sustainable development. In Proceedings of the 30th International Symposium on Agricultural Engineering" Actual Tasks on Agricultural Engineering" (pp. 171-184). HINUS.
- Vaupel, A., Küsters, M., Toups, J., Herwig, N., Benedikt Bösel, & Lukas Beule. (2025). Trees shape the soil microbiome of a temperate agrosilvopastoral and

syntropic agroforestry system. Scientific Reports, 15(1). https://doi.org/10.1038/s41598-025-85556-4

- Zampolini, M. (2023). Contrasting the banalisation of tourism. Architectural, landscape and micro-urbanistic design of an accommodation facility in the Azores. Seminario Internacional de Investigación en Urbanismo, (15).https://doi.org/10.5821/siiu.12712

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The island has a type of nature I had never seen or imagined before.

Coming to Aruba, I imagined seeing perfect white beaches, one of the island's signature features. However, I did not expect to see Aruba's wilder side of nature, which is even more breathtaking to me. With its forests of cacti, hidden pink caves, colorful fish, turtles, natural pools, and rough waves, the island has a type of nature I had never seen or imagined before. A particularly memorable experience was exploring a cave that was somewhat risky to access because of the powerful waves crashing at the entrance. At first, I was hesitant to enter, but once inside, I was amazed by the entirely pink cave walls, blending with the soft blue colors of the water. I could see and feel the warmth of sunrays piercing through the small openings in the rocks, contrasting with the cave's cool and shadowy environment. Sharing these moments with my friends, who encouraged me to see and explore things I would not have otherwise, made my time in Aruba even more meaningful. Discovering the island's wild beauty, I felt like I got to know the island better, forming a more meaningful connection to it.

Another unforgettable part of my Aruban experience was Manuelita, the car I shared with Inger, Kaja, and Gabi. The car became a defining element of our adventure, taking us wherever we wanted to go and offering us the opportunity to explore the island as we wished. We treated Manuelita like our baby, always being patient with her, especially when encountering some challenges along the way. We always left Manuelita unlocked, thinking the car wasn't possible to lock, which, in hindsight, reflects the island's relaxing charm.

Further, getting to know the community and culture of Aruba has been enriching. The islanders' generosity and openness toward strangers, always willing to offer their full attention and time, have been inspiring to me. Another

significant part of getting to know the people of the island was sharing the class with students at the University of Aruba. Also, the classes of Eric Mijts, an inspiring teacher, have been a special learning experience for me. He encourages his students to question various topics specific to Aruba, but ultimately applicable across different contexts. Every class has broadened my understanding of the interconnectedness of global challenges, offering valuable perspectives and new ideas each time.

Most importantly, I have created so many fun memories together with my peers from Utrecht University, defining my adventure in Aruba. Each of them is passionate, hardworking, and has a unique personality. Lastly, my roommate and dear friend Inger, with whom I've shared night and day on the island, has been a source of kindness and safety. She looks like an angel and truly is one, my guardian angel of Aruba.

Financial Empowerment for Aruba's Community to Foster Sustainable Agricultural Technologies

Sophie Spoor

1 Introduction

Aruba's main industry sector is the international tourism industry, which can be seen as a tool for economic growth. However, the heavy focus on the tourism industry contributes to Aruba's dependence on imports for access to food, making the island very vulnerable to global market fluctuations and supply chain disruptions (De Kort et al., 2023). On top of this, challenges for food production are compounded by high energy costs, water scarcity, climate change, and lack of labor capacity (Boyer et al., 2024). This research addresses the issues regarding food security in Aruba by focusing on financing innovative farming technologies on the island (De Kort et al., 2023). Agricultural technologies enable controlled growing environments for crops, reducing the dependence on external environmental conditions. Since the island often faces high temperatures and inconsistent precipitation, controlled farming systems offer an effective approach for growing crops in Aruba all-year round and achieving higher yields. Furthermore, these agricultural methods can optimize the use of scarce land and water resources in Aruba, offering approaches to adapt to Aruba's limited resources. Because of the reasons mentioned above, innovative agriculture provides a more economically viable approach in Aruba compared to traditional farming. Traditional farming requires more land and water for crop growth, and exposes crops to external environmental conditions, which could cause damage to the plants (Saxena et al., 2024).

This paper examines how increasing the adoption of agricultural technologies in Aruba could be achieved through sustainable financing. Sustainable finance is an effective strategy for resource allocation towards more circular agricultural development. Sustainable finance, as defined by Vargas (2023), refers to financial practices that incorporate Environmental, Social, and Governance (ESG) factors to create long-term value, while addressing sustainability challenges. This investment approach empowers existing and potential farmers in Aruba with necessary resources to transition to more responsible agricultural practices.

Moreover, the financial challenges faced by the Aruban community for increasing local food production will be investigated. Specifically, it explores how the high investment costs associated with innovative and sustainable agricultural practices are compounded by insufficient financial support mechanisms. The insufficient access to monetary support for the primary sector in Aruba creates a significant barrier to adopting sustainable farming technologies. Recognizing the community's need for enhanced food security, this study aims to bridge the gap between food security goals and the availability of financial resources.

The following chapters will explore the current state of food security in Aruba, analyze the role of sustainable finance by private and public organizations in advancing

agricultural technologies, and discuss the critical role of government policies in fostering growth within the primary sector. Therefore, this study aims to highlight the complex interconnections between sustainable finance, food security, and community empowerment on the island. By identifying strategic financial approaches to overcome barriers to food production, this research offers practical recommendations to enhance food security in Aruba.

2 Methodology

This study examines the financial potentials and constraints to improve food security in Aruba by adopting a combination of qualitative data collected through semi-structured interviews and a comprehensive literature review.

2.1 Data Collection

The semi-structured interviews, initially conducted as a part of a Consultancy Project about the potential for increasing food security in Aruba, provide context-specific insights for this research. These interviews address important perspectives from stakeholders including, farmers, government officials, and finance experts. Participants discussed key issues, such as access to finance, the impact of government policies and regulations, and the effects of climate change on farming. To provide context-specific data, direct quotes from interviews were used to address important insights from stakeholders.

Additionally, a comprehensive literature review was conducted, using academic literature, government reports, and industry publications to establish a theoretical framework.

This study provides a comprehensive understanding about the financial challenges affecting food security in Aruba. By integrating theoretical insights from literature with perspectives from the local community of Aruba, this study contextualizes the challenges and opportunities for financing food production within Small Island States.

3 Literature Review and Interview Results

3.1 The Interconnected Challenge of Sustainable Finance and Food Security in Aruba

As mentioned before, the high initial investment and energy costs for agricultural technologies together with the lack of access to capital for local farmers, impose a significant barrier to increase food security in Aruba. As a governmental official explains, ‘’The investment cost is always high for these types of technologies” (personal communication, March 15, 2025), highlighting the need for improved financial assistance to encourage farmers to adopt innovative farming practices. Furthermore, other key stakeholders have emphasized the direct impact of climate change, water scarcity, and high electricity costs as a challenge to the agricultural viability of the island (Boyer et al., 2024). During an interview a farmer mentioned, “Last summer was harsher than before, meaning that we needed more energy capacity” (personal communication, March 14, 2025). Given the island’s vulnerability to climate change, it is crucial for the island to transition to more circular business practices. This means, there should be more financial support for farmers to apply sustainable farming practices, such as renewable energy and rainwater capturing systems. Additionally, investing in more sustainable methods, resource efficiency could be improved, reducing operation costs.

Finance for enhancing food production typically comes from four main sources: public and private domestic financing, and public and private foreign financing. For Aruba, a combination of these investment forms is essential to ensure enough resources for long term food security. While

public funds and policy could help enable an environment to increase food production, private investments play an important role for scaling up farming businesses (FAO et al., 2024). For this reason, financial institutions, could play a critical role by prioritizing environmentally and socially responsible investments (Uzsoki, 2020). In order to generate long-term sustainable value, sustainable banking incorporates ESG considerations into financial decision-making. Banks could use sustainable ratings and assessments to analyze the environmental impact of agricultural projects. Moreover, to make a sustainable transition banks should provide guidance to assist their customers in making a shift to more circular operations (Weber and Feltmate, 2016).

Sustainable finance offers an effective strategy for increasing food production in Aruba in a sustainable way. By integrating sustainability principles such as Sustainable Development Goals (SDG's) and ESG factors into financial decision making, sustainable financing can be used as a tool for businesses to enable a sustainable transition. Sustainability can be promoted to generate long-term value for investors and business. Long-term value results in competitive advantage, sustained growth, and innovation, often measured through non-financial indicators, such as market position (Vargas, 2023). Consequently, sustainable finance can provide businesses with the opportunity to transition towards more circular practices (Alterescu & Caguioa, 2020). Additionally, incorporating circularity into business operations can lower expenses, mitigate risks, and improve market reputation (Bem et al., 2022). Along with this, studies show that businesses with strong ESG performance tend to have better financial outcomes. As a result, there is an increasing interest in sustainable investments as more investors become aware of the hazards associated with climate change (Edmans & Kacperczyk, 2022). In the context of increasing food security in Aruba, this could mean prioritizing investments in sustainable agriculture (Vargas, 2023).

On the other hand, farmers' perspectives in Aruba suggest that moving toward more environmentally friendly farming methods is seen as a high investment risk. This high-risk perception of transitioning to more sustainable practices, imposes a barrier to enhance sustainable food production in Aruba. Therefore, an expert in renewable energy suggested, ''You should lower the risks, such as the interest rates, to enable momentum for people to experiment with circular technologies on the island and give them the confidence to further invest in it" (personal communications, March 7, 2025). This indicates the need for financial support, such as lower interest rates and flexible repayments terms, to mitigate financial risks and encourage the community to apply circular practices into their businesses. (Schoenmaker & Schramade, 2024). Besides, traditional financial evaluation methods should become more flexible to accommodate investments in evolving sustainable technologies. For instance, new evaluation methods for sustainable financing could include longer payback periods, scenario planning, and positive externalities to accurately assess the value of investments (Bem et al., 2022).

3.2 Micro-Crediting and Financial Inclusion

Microfinance provides small-scale loans to individuals who cannot get access to financial services, such as traditional banking (B. Balkenhol, 2007). Thus, micro-crediting helps entrepreneurs start or expand their businesses, contributing to local economic development and diversity (Vargas, 2023). Moreover, microfinancing promotes financial inclusion by removing barriers, such as collateral, often imposed by traditional financial institutions. In Aruba, micro-crediting company Qredits has contributed to creating new jobs and businesses, fostering the island's economic resilience (Qredits Aruba, 2024).

The Agri-Loan Program, initiated by Qredits, is an example of how microfinancing in Aruba has helped farmers to finance their farming businesses. The program was

initiated by both the government and Qredits, utilizing a governmental fund to support the Aruba's primary sector. This example demonstrates how strategic funding initiatives and collaboration are crucial for achieving enhanced food production in Aruba. Also, the Agri-Loan program included an educational component, which combined financial support with training and mentorship to ensure its financing model provides farmers with the necessary skills to manage their businesses. In addition, Qredits encourages farmers to adopt modern agricultural technologies and educates participants about sustainable business practices. Furthermore, financial obstacles that farmers in Aruba encounter are addressed by the Agri-Loan's low 2% interest rate and six-month interest only payment period (Qredits Aruba, 2024). This initiative shows how microfinance could be used as an effective strategy for fostering sustainable company development, diversifying businesses, ensuring economic stability, and forming inclusive economies (B. Balkenhol, 2007).

3.3 Prioritising Food Production in Governance

Although Aruba's tax policies currently favor farmers by exempting them from taxation, farmers are unsure about the stability of these existing policies. This uncertainty creates an obstacle for long-term investment plans by potential farmers. To prove this point, one farmer mentioned, ''It is difficult to invest if you do not know if the tax policy is going to stay" (personal communication, February 27, 2025).

Moreover, key stakeholders have mentioned that additional incentives that are not financially related should be implemented in Aruba, such as improved access to renewable energy and rainwater capture systems on the island. This would enable farmers to adopt sustainable practices and reduce operational costs more easily (Boyer et al., 2024).

Therefore, governmental support, through fiscal policies and regulations, is essential in shaping the financial landscape for adopting sustainable agriculture (Thomson et al., 1999). Concerns were raised by community stakeholders regarding the lack of prioritization of the primary sector in Aruba. The ambiguity around government commitment and the need for a more consistent policy framework, were highlighted by one farmer who said, ''Knowing what the government will or will not do, is always difficult to say" (personal communication, March 14, 2025). Macroeconomic factors, such as trade policies and inflation, impact food security by influencing food costs and agricultural development in Aruba. Particularly, fiscal policies are crucial in creating an economic environment that could support the growth of Aruba's food production industry. Thus, governmental decisions are critical in supporting the food industry on the island (Thomson et al., 1999). A governmental official stated, ''To strengthen food security, Aruba needs structural economic adjustments that improve the business environment for local food production" (personal communications, March 15, 2025). This statement further emphasizes the need for long-term policy reforms to foster a stable and supportive environment for local agriculture. To ensure effective financing towards food security, it is crucial to focus on initiatives that directly enhance local food production (FAO et al., 2024).

The new Aruban government has published its priorities for 2025-2028. While focusing on economic stability, food security is not prioritized in the new plans, despite its critical role in economic resilience and sustainability of the island (Governance Program Aruba, 2025). By making food security a priority as well, Aruba could attract both national and international funding to enhance its agricultural sector. Further, policy recommendations should include the primary sector in macroeconomic decision-making ensuring that fiscal policies actively support domestic food production directly (FAO et al., 2024). The integration of food security into the government's priorities requires a proactive approach to funding strategies and policies that

support the expansion of food production by local farmers. Therefore, creating an environment that fosters sustainable agricultural development is crucial to increase Aruba's economic resilience and food security.

Additionally, the government should encourage more cooperation between public and private sectors to enforce structural changes to strengthen food production. Such public-private collaboration could leverage mobilizing resources and expertise to co-finance sustainable farming practices and share the risks associated with transitioning to new technologies (FAO et al., 2024). As expressed by a governmental official, ''The Central bank of Aruba is interested in exploring more possibilities to enhance the primary sector. While they are not a lending bank, I would recommend them to give advice to other banks to prioritize the primary sector" (Personal Communication, March 15, 2025). This approach aligns with public-private collaboration as well as sustainable banking, where banks provide advisory services for sustainable investments (Weber and Feltmate, 2016).

4. Discussion

The findings of this study showcase the importance of providing sustainable finance to increase food security in Aruba. Due to the island's vulnerability to climate change, farmers in Aruba should implement adaptive agricultural systems to ensure food production remains economically viable (FAO et al., 2024). However, these agricultural technologies come with higher investment costs. Therefore, integrating sustainability principles for financing agricultural businesses is essential to enhance long-term food security on the island.

4.1 Recommendations

Prioritize food security through sustainable investments: The Aruban government should prioritize enhancing food security by investing in agricultural technologies. By incorporating sustainable finance in such investments, sustainable transitions in farming can be achieved. Promoting sustainable farming practices, includes providing flexible financial terms, such as reduced interest rates, extended repayment periods, and new financial evaluation methods (Bem et al., 2022).

Strengthen microfinance initiatives: Programs for microfinancing initiatives should be expanded, making sure they maintain flexible financial terms (Qredits Aruba, 2022). Additionally, the government should continue with focusing on providing funds to Qredits for them to continue enable farmers to start or expand their business (Balkenhol, 2007).

Create long-term policy frameworks: A comprehensive, long-term policy framework that specifically prioritizes food security and supports sustainable agriculture should be developed (Thomson et al., 1999). Such framework must prioritize investments that yield both financial returns and contribute to the island's long-term food security and climate adaptation goals.

Foster public and private collaboration: To effectively strengthen food production on the island, public and private sectors should cooperate to combine and maximise resources and expertise (Alterescu and Caguioa, 2020).
Foster sustainable transitions within farming ventures: Ensure that farmers have access to sustainable long-term financing for them to expand and apply sustainable practices. Appropriate discount rates could foster sustainable business choices, considering future social and environmental costs are crucial for an island with high vulnerability to climate change (Schoenmaker and Schramade, 2024).

5 Conclusion

Aruba's dependence on food imports is a challenge that requires a transdisciplinary approach to be addressed

(Seidl et al., 2013). This paper focused on prioritizing investments in sustainable agriculture technologies to increase food production and foster economic resilience in Aruba. Increasing finance for food security in Aruba comes with several contextual social, economical, and political challenges that need to be addressed through a multifaceted approach by engaging different stakeholders. Allocating more funding to food production requires expanding (micro)finance initiatives by both public and private financial institutions, developing long-lasting and transparent policy frameworks, and fostering active collaboration between various stakeholders and organizations. These efforts directly contribute to the island's resilience towards economic, social, and environmental challenges. To ensure long-term effectiveness of these strategies ongoing research, collaboration, and dedicated implementation are needed.

References

- Alterescu, S., & Caguioa, R. (2020). Engaging private sector in NDC implementation - Assessment of private sector investment potential in the agriculture sector. In L. Brumer (Red.), UNDP [Report]. https://climatepromise.undp.org/sites/default/files/research_report_document/undp-ndcsp-paraguay-priv-sector-deloitte-exec-sum.pdf
- AVP-Futuro. (2025). Governance Program AVP-Futuro 2025-2028. National Library of Aruba, Aruba Collection
- Balkenhol, B. (2007). Microfinance and Public Policy: Outreach, Performance and Efficiency
- Bem, A., Daszynska-Zygadlo, K., Hajdíková, T., Jáki, E., & Ryszawska, B. (2022). Sustainable Finance in the Green Economy. In Springer proceedings in business and economics. https://doi.org/10.1007/978-3-030-81663-6
- Boyer, A., Horton. J., Millán, M., Grosjean, C., Ramón Ernesto, A., Lopez, E., Wrede, P., Rendell Ernest de Kort., Justiniano, I., Regis, C. (2024).Building Resilience in Aruba's Food Security During the Pandemic and Beyond. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099055001092318003
- De Kort, R., Obispo, S., Carmona Baez, A., Echteld, E., Mijts, E. (2023). Strengthening Economic Resilience in Small Island States: A Situational Analysis of Food Entrepreneurship, with a Focus on the Cucumis Anguria Cucumber in Aruba. In N. Faraclas, R. Severing, E. Echteld, W. Rutgers, & S. Delgado, (Eds.), Southern Entanglements: Southern Epistemologies, Southern Praxes and The Languages, Literatures and Cultures of the Dutch Caribbean and Beyond (pp. 53-70). University of Curaçao/University of Puerto Rico
- Edmans, A., & Kacperczyk, M. (2022). Sustainable finance. Review Of Finance, 26(6), 1309–1313. https://doi.org/10.1093/rof/rfac069

- FAO, IFAD, UNICEF, WFP and WHO. 2024. The State of Food Security and Nutrition in the World 2024 – Financing to end hunger, food insecurity and malnutrition in all its forms. Rome. https://doi.org/10.4060/cd1254en
- Qredits Aruba. (2022). Social Impact Report. https://s3.eu-central-1.amazonaws.com/webstores-qredits-nl/04/qredits-sociaal-jaarverslag-aruba-online.pdf
- Saxena, A., J, A. R., Ramesh, B., Fande, A., Chandra, P. K., Sethi, V. A., & Al-Farouni, M. (2024). Advancing Sustainable Agriculture through Resource Efficiency. E3S Web Of Conferences, 507, 01006. https://doi.org/10.1051/e3sconf/202450701006
- Schoenmaker, D., & Schramade, W. (2024). Which discount rate for sustainability? Journal Of Sustainable Finance And Accounting, 3, 100010. https://doi.org/10.1016/j.josfa.2024.100010
- Seidl, R., Brand, F. S., Stauffacher, M., Krütli, P., Le, Q. B., Spörri, A., Meylan, G., Moser, C., González, M. B., & Scholz, R. W. (2013). Science with Society in the Anthropocene. AMBIO, 42(1), 5–12. https://doi.org/10.1007/s13280-012-0363-5
- Thomson, A. M., Metz, M., & Nations, F. A. A. O. O. T. U. (1999). Implications of Economic Policy for Food Security: A Training Manual. Food & Agriculture Org.
- Uzsoki, D. (2020). Sustainable Investing Today. In Sustainable Investing: Shaping the future of finance (pp. 3–7). International Institute for Sustainable Development (IISD). http://www.jstor.org/stable/resrep22000.4
- Vargas, C. (2023). Sustainable Finance Fundamentals. https://doi.org/10.4324/9781003274735
- Weber, O., & Feltmate, B. (2016). Sustainable banking. In University of Toronto Press eBooks. https://doi.org/10.3138/9781442629325

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Life here had a rhythm.

From the start, this felt different from anything I'd done at university. Research wasn't just about sitting behind a screen, it meant talking to people, gathering real-world insights, figuring things out as we went. There was a lot of freedom in how we approached the project, but that also came with real responsibility. Our team of eight had to blend different skills, ideas, and ways of working. Even with the challenges we faced, we pushed through and made it happen.

Being from Cyprus, another island, Aruba felt oddly familiar but completely new at the same time. Life here had a rhythm that I missed from back home, the way people connect, the ocean, the beach sunsets, the food, the warm, welcoming community. I even got the chance to windsurf here, something I had done back home but doing it again in Aruba, with friends, made it feel like a whole new experience. I also ended up driving more than I did back home, and on the opposite side of the road from Cyprus too, another skill unlocked along the way.

More than anything, this project pushed me out of my comfort zone. I didn't see myself as someone who enjoys being overly social, doing interviews, but talking to people and hearing their perspectives turned out to be one of the most interesting and main parts of the whole experience. The Aruban community was open and willing to share, which made our research feel real and meaningful.

Beyond research, this experience was about people. I was lucky to go through this with a great team, and teachers and sharing it with a close friend, made it even more special. Living, working, and exploring together created a whole set of memories.

This project was one of the first times I saw my academic skills applied in a real-world setting. It made me think

differently about research, about collaboration, and about what I want to do next. I've always had the urge to travel, explore, and experience different places, and this program was that and more.

Evaluating renewable energy integration for innovative agriculture in Aruba

Katerina Kyriakidou

1 Introduction

Small Island Developing States (SIDS) are a group of countries that face significant environmental, and socio-economic challenges (UN, n.d.), which affect their ability to build resilient and sustainable agricultural systems. Aruba, as a SIDS in the Caribbean, is mostly dependent on food imports, has limited freshwater availability, and relies heavily on fossil fuels for energy. These factors create vulnerabilities in food security, making the island prone to external disruptions (de Kort et al., 2024). The COVID-19 pandemic further proved the need for increased self-sufficiency and resilience, leading to more efforts to expand the agricultural sector of the country (Boyer et al., 2020). To strengthen food security and transform the agricultural sector, the Government of Aruba (GoA) has introduced a new Primary Sector Policy, which aims to develop a resilient and stronger agricultural sector through increased commercial food production, financial support for farmers, and investments in innovative agricultural technologies. As part of this policy, the Agri Innovation Park and farmer's markets will be established, and annual funding of 2.5 million florins will be allocated to develop agricultural infrastructure (GoA, 2025).

While Aruba's agricultural sector remains small compared to industries like tourism, there has been an increase in local farmers (Falcon, 2024). However, due to harsh climate conditions and poor soil quality, traditional farming methods are not always possible. This has led to the exploration of innovative agricultural practices, including hydroponics and vertical farming, as alternatives to soil-based farming. Both methods improve resource efficiency and reduce land use (Rajendran et al., 2024), making them suitable for islands with limited arable land, like Aruba. Nevertheless, many agricultural innovations use high amounts of energy to operate, in Aruba most of this energy still comes from fossil fuels. Given Aruba's hot and semi-arid climate, cooling demands further increase electricity use, raising concerns about environmental impact, cost and long-term sustainability. Integrating renewable energy sources could help mitigate these challenges.

This paper primarily focuses on solar energy, even though both solar and wind energy show potential for being integrated with innovative agricultural technologies in Aruba. The central research question guiding this study is: "How feasible is the integration of renewable energy into Aruba's innovative farming systems?"

2 Literature Review

2.1 Renewable Energy in Agriculture

To understand the role of innovative agricultural technologies in Aruba, it helps to first look at what they

entail. Hydroponics and vertical farming are two approaches that are presently implemented in Aruba. Hydroponics is a soilless farming method where plants grow in nutrient-rich water within containers (Cassidy et al., 2020), while vertical farming maximises space by growing crops in stacked layers, often in controlled environments (Mir et al., 2022). These agricultural systems are typically used in greenhouses, where the climate can be carefully controlled to support optimal plant growth. The reliance of these technologies on water circulation, ventilation, and artificial lighting results in high energy consumption. This is where renewable energy sources, such as solar, wind, and biomass, become especially important for making agriculture more sustainable (Bathaei & Štreimikienė, 2023). Solar power is especially suitable for SIDS like Aruba, given its high levels of sunlight and the decreasing costs of solar panel systems. Wind energy is another potential option, as Aruba has consistently strong winds, particularly in coastal and elevated areas (Ruiz, 2024). Small wind turbines could theoretically help power farms, but their efficiency depends on wind patterns, which can be unpredictable and inconsistent compared to solar power. This variability makes it difficult to guarantee a stable energy supply for farming systems that require continuous electricity, such as hydroponics and vertical farming (Tummala et al., 2016). Additionally, small wind turbines are expensive to install and maintain, particularly in areas where wind speeds fluctuate. They also require more space, and their noise and visual impact can be problematic for smaller farms (Nazir et al., 2022). As a result, solar energy is generally a more feasible and scalable approach for powering Aruba's innovative agricultural sector. As mentioned in the introduction, this paper primarily focuses on solar energy because while wind energy has potential, its application in farming can be challenging.

2.2 Agrivoltaics

One promising approach is agrivoltaics, which involves installing solar panels above crops. This method allows for both food production and electricity generation on the same land while also creating shade that helps reduce water loss and heat stress on plants (Prasad et al., 2025). Agrivoltaics is more commonly applied in soil-based agriculture, but since its core concept is the dual use of land for both agriculture and energy production, it can also be adapted to innovative farming systems. In particular, it can be implemented in greenhouse-based agriculture to help meet the farm's energy demands. In particular, it can be implemented in greenhouse-based agriculture to help meet the farm's energy demands. The shade from solar panels can help keep greenhouses cooler, reducing the need for cooling, while also providing renewable energy to power these systems more sustainably (Torrente et al., 2024). Implementing agrivoltaics also comes with challenges; for example, not all existing greenhouses can structurally support solar panels, and solutions must be developed to store excess energy efficiently (Mamun et al., 2022).

3 Methodology

This section describes current insights in energy consumption in agricultural technologies and perspectives on renewable energy integration. The study aimed to quantify the energy requirements of innovative agricultural technologies to assess their operational needs and potential for renewable energy integration. While the primary aim is to evaluate the feasibility of renewable energy adoption in these systems, understanding the energy consumption is important for contextualising the scale of energy demand. This helps assess how realistic it is to transition these farming methods to renewable energy sources in Aruba, considering the local energy mix.

Hydroponics is more commonly practiced in Aruba than vertical farming, making it more feasible to gather real-world energy use data for analysis. While vertical farming is considered, energy data for this method is less readily available. Additionally, energy use calculations

for hydroponics are provided more as an example to give context, rather than being the main focus of this study.

To calculate the direct energy needs of hydroponic and vertical farming systems energy use data for cooling, ventilation, water pumping, and artificial lighting was used. Aruba mainly relies on fossil fuel-generated electricity (>80%), and much less on renewables (<20%) (WEB, n.d.). This does not only lead to high energy costs, but also to a high carbon footprint of energy production.).

The total direct energy required per kg of food produced was calculated as follows:

$$E_{total} = E_{cooling} + E_{ventilation} + E_{pumping} + E_{lighting}$$

The carbon footprint is also calculated by multiplying energy use by Aruba's CO_2 emission factor, in order to assess the actual environmental impact of energy consumption. For example, for hydroponic farms, data such as the average weight of a head of lettuce, annual energy consumption in kWh, and total food production output per year (heads of lettuce) were collected from interviews with hydroponic lettuce farmers. The total annual lettuce production in kg was calculated by multiplying the number of heads of lettuce produced per year by the average weight of one head of lettuce. The energy intensity of lettuce production was calculated using the equation:

$$Energy\ per\ kg\ of\ food(\frac{kWh}{kg}) = \frac{Total\ annual\ energy\ use\ (\frac{kWh}{year})}{Total\ annual\ lettuce\ production\ (\frac{kg}{year})}$$

This value was then converted to megajoules per kilogram (MJ/kg) by multiplying by 3.6, as 1 kWh = 3.6 MJ:

$$Energy\ per\ kg\ of\ food\left(\frac{MJ}{kg}\right) = \frac{kWh}{kg} * 3.6$$

Using MJ instead of kWh allows for easier comparisons between different energy sources. Since hydroponic farming involves multiple energy inputs such as electricity for pumps, lighting, and ventilation, MJ provides a standardised unit that accounts for total energy use.

Since hydroponic farms use desalinated water and fertilizers (Innovative farmer, March 14, 2025), the indirect energy demand, such as the energy needed for water desalination and nutrient production, was also considered using data from literature.

In addition to gathering numerical data, interviews were conducted with people working in agriculture and energy. These conversations provided firsthand views on agrivoltaics, regulatory constraints, financial feasibility, and technical challenges.

The information was analysed based on the same themes, identifying common concerns and opportunities across different sectors. While these interviews were not conducted exclusively for this study, they offer valuable insights that align with the main themes of this research.

4 Results

The results from the energy calculations and interviews help answer the research question by showing how renewable energy can meet the energy needs of innovative farming in Aruba. The findings show both the opportunities and challenges, which are important for understanding how practical it is to use renewable energy in Aruba's farming systems. The findings are organised into main themes, including energy use, feasibility of agrivoltaics and key challenges related to policy, financial investment, and infrastructure.

4.1. Energy Use

Approximately 50% of the total direct energy use in hydroponic farms is dedicated to cooling, 15-20% to

ventilation (which is mainly used during hotter months), and 30% to pumping. These percentages provide a breakdown of how energy is allocated for the main components of hydroponic farming.

Energy demand for hydroponic farming was calculated using the equations outlined in the Methods section. For hydroponic farms producing lettuce, with an average head of lettuce weighing 250g (Innovative farmer, personal communication, March 24, 2025), the energy consumption was found to be approximately 40 MJ/kg of produce. This value represents total direct energy use (first equation in the methods section) and gives an overview of energy intensity.The carbon footprint was found to be 5.93kg CO2-eq/kg. While hydroponics offers clear advantages in water and land use, the carbon footprint raises concerns about sustainability, especially if the system depends on fossil-fuel-based electricity.

Indirect energy use is not detailed in numbers here, as the focus is on renewable energy integration for operations on the farm specifically.

Vertical farming needs even more energy than hydroponics because it's usually practiced indoors and depends on artificial lighting for plant growth. While hydroponic farms mainly use energy for cooling and pumping, vertical farms require constant lighting, which increases their electricity use (Arcasi et al., 2023). However, if vertical farms in Aruba used natural sunlight the energy demand difference between the two technologies would be less significant.

4.2 Feasibility and Challenges of Agrivoltaics in Aruba

Agrivoltaics have potential benefits in Aruba's climate, especially by creating a microclimate that could help protect crops. However, there is limited local research or trials on its effectiveness, making it difficult to determine which crops would thrive under solar panels. Trial projects are needed to test different setups before they can be widely used (Innovative farmer, personal communication, March 14, 2025).

4.3 Policy and Financial Barriers to Renewable Energy Adoption

One regulatory challenge is the 100 kW cap on solar energy capacity for businesses. This restriction prevents larger farms from generating more energy than they need, limiting their ability to sell excess energy back to the grid. Interviewees mentioned that since energy policy in Aruba is politically sensitive, regulatory changes could be slow-moving, especially if they might impact electricity prices.

The high upfront costs make it difficult for farmers to adopt renewable energy. While solar power can reduce costs over time, many farmers find it hard to secure affordable loans. Commercial loans for solar energy often come with high interest rates (up to 12%), which makes investing in these systems challenging (Energy expert, personal communication, March 7, 2025).

4.4 Infrastructure and Grid Limitations

The current agricultural infrastructure in Aruba is not designed to support, for example, agrivoltaic systems. Greenhouses are not built to hold the additional weight of solar panels, meaning structural changes would have to be done (Innovative farmer, personal communication, March 14, 2025). As seen in the literature review section, this point is also supported by previous research.

Additionally, the grid in Aruba has limitations when it comes to energy distribution. While 20% of the electricity is generated from renewables, the grid is not yet fully set up to handle more decentralised solar energy. Although excess energy can be sold to the grid, there are limits on how much can be fed back without causing grid instability (Energy expert, personal communication, March 7, 2025).

4 Discussion & Conclusion

This study points out the potential for renewable energy to make Aruba's agriculture more sustainable, particularly through innovative farming technologies. These systems require significant energy, with hydroponic farms consuming about 9 MJ per kilogram of produce, as shown in the findings of this study. This high energy demand has environmental impacts, especially when much of that energy still comes from fossil fuels. Integrating renewable energy, such as solar or wind power, could help reduce this environmental footprint, making these farming methods more sustainable in the long run.

Agrivoltaics present an interesting opportunity, particularly in Aruba's climate, as it could provide energy while simultaneously protecting crops through the creation of microclimates. A major challenge though, is that most greenhouses are not designed to support the weight of solar panels, which would require structural modifications, as mentioned by interviewees and as pointed out in literature. This adds to the already high costs, making it more difficult for farmers to invest in renewable energy without financial help. The high interest rates on loans for renewable energy projects make this issue harder. Better financing options, like subsidies or lower-interest loans, could help encourage more farmers to adopt these technologies.

In addition to financial concerns, policy limitations also pose challenges. For example, the 100 kW limit on solar energy generation for businesses prevents farms from producing and selling excess energy, limiting their ability to make the most of solar power. If possible, the refinement of these policies could help boost renewable energy in farming, but the political sensitivity of energy policy in Aruba may slow down these changes. On a positive note, initiatives like the Primary Sector Policy and AGRIFUND already support agricultural development, and they could be a starting point for incorporating renewable energy into these efforts.

Pilot projects to test agrivoltaics under local conditions would be a promising next step. These trials could help determine which crops benefit most from the shading and whether any current greenhouse structures can support the required modifications. Additionally, pilot studies could refine the economic and technical feasibility of agrivoltaics before larger-scale implementation.

In conclusion, this study shows that integrating renewable energy into Aruba's agriculture could improve sustainability, but there are important challenges to overcome. The research question, "How feasible is the integration of renewable energy into Aruba's innovative farming systems?", can be answered by addressing issues such as policy, financing, and infrastructure. By tackling these challenges, Aruba can move toward a more sustainable and self-sufficient agricultural system.

References

- Arcasi A., Mauro, A. W., Napoli, G., F. Tariello, & G.P. Vanoli. (2023). Energy and cost analysis for a crop production in a vertical farm. Applied Thermal Engineering, 239, 122129–122129. https://doi.org/10.1016/j.applthermaleng.2023.122129
- Bathaei, A., & Štreimikienė, D. (2023). Renewable Energy and Sustainable Agriculture: Review of Indicators. Sustainability, 15(19), 14307. https://doi.org/10.3390/su151914307
- Boyer M., Horton J., Millán M. F., Grosjean C. F. R., Arias Ramón E., Lopez Elena M., Wrede P., de Kort R. E., Justiniano I. and Chapman R\. (2020). Building Resilience in Aruba's Food Security During the COVID-19 Pandemic and Beyond. World Bank: Washington D.C
- Cassidy, S., Coulter, M., Finkelston, T., Hoherchak, K., Mendes, A., Ott, G., Patton, C., Stein, K., Etienne, B., Louis, G., & Lerdau, M. (2020). Hydroponic Crop Cultivation (HCC) for Food Security in Small Island Developing States. 1–5. https://doi.org/10.1109/sieds49339.2020.9106658
- Chel A., & Kaushik, G. (2010). Renewable energy for sustainable agriculture. Agronomy for Sustainable Development, 31(1), 91–118. https://doi.org/10.1051/agro/2010029
- de Kort, R., Jong, R. D., Hoogstad, E., Baez, A., Echteld, E., & Mijts, E. (2024). Exploring amplified Food Security vulnerabilities in Curacao, Aruba and Sint Maarten amidst the COVID-19... ResearchGate; https://www.researchgate.net/publication/388143687_Exploring_amplified_Food_Security_vulnerabilities_in_Curacao_Aruba_and_Sint_Maarten_amidst_the_COVID-19_pandemic_Island_Innovation_Policy_Brief
- Falcon, A. (2024). Unveiling Hotspots in Hydroponic Lettuce Production . In Mijts, E. & Ballantyne, J. UAUCU Student Research Exchange Collected Papers 2024. pp. 73 - 78.
- Government of Aruba. (2024). First step taken to finance the agricultural industry (Agrifund). Government of Aruba. https://www.gobierno.aw/en/ first-step-taken-to-finance-the-agricultural-industryagrifund
- Government of Aruba. (2025). Programa di Gobernacion AVP-Futuro 2025-2028 https://coleccion.aw/show/?BNA-DIG-GOBIERNO-GABINETEAVPFUTURO-2025-2028
- Government of Aruba. (2024). First step taken to finance the agricultural industry (Agrifund). Government of Aruba. https://www.gobierno.aw/en/ first-step-taken-to-finance-the-agricultural-industryagrifund
- Mamun, M. A. A., Dargusch, P., Wadley, D., Zulkarnain, N. A., & Aziz, A. A. (2022). A review of research on agrivoltaic systems. Renewable and Sustainable Energy Reviews, 161, 112351. https://doi.org/10.1016/j.rser.2022.112351
- Mir, M. S., Naikoo, N. B., Kanth, R. H., Bahar, F. A., Bhat, M. A., Nazir, A. & Ahngar, T. A. (2022). Vertical farming: The future of agriculture: A review. The Pharma Innovation Journal, 11(2), 1175-1195.
- Nazir, M. S., Wang, Y., Bilal, M., & Abdalla, A. N. (2022). Wind Energy, its Application, Challenges, and Potential Environmental Impact. Handbook of Climate Change Mitigation and Adaptation, 899–935. https://doi.org/10.1007/978-3-030-72579-2_108
- Prasad, R. D., Chand, D. A., Lata, S. S. S. L., & Kumar, R. S. (2025). Beyond Energy Access: How Renewable Energy Fosters Resilience in Island Communities. Resources, 14(2), 20. https://doi.org/10.3390/resources14020020
- Rahman, M. M., Khan, I., Field, D. L., Techato, K., & Alameh, K. (2022). Powering agriculture: Present status, future potential, and challenges of renewable energy applications. Renewable Energy, 188, 731–749. https://doi.org/10.1016/j.renene.2022.02.065
- Rajendran, S., Tenzing Domalachenpa, Arora, H., Li, P., Sharma, A., & Gaurav Rajauria. (2024). Hydroponics:

Exploring innovative sustainable technologies and applications across crop production, with Emphasis on potato mini-tuber cultivation. Heliyon, 10(5), e26823–e26823. https://doi.org/10.1016/j.heliyon.2024.e26823

- Ruiz, I. (2024). Offshore Wind Generator Possibilities in Small Island States; Preliminary Results. In Mijts, E. & Ballantyne, J. UAUCU Student Research Exchange Collected Papers 2024. pp. 19 - 26.
- Torrente, C. J., Reca, J., López-Luque, R., Martínez, J., & Casares, F. J. (2024). Simulation model to analyze the spatial distribution of solar radiation in agrivoltaic Mediterranean greenhouses and its effect on crop water needs. Applied Energy, 353, 122050. https://doi.org/10.1016/j.apenergy.2023.122050
- Tummala, A., Velamati, R. K., Sinha, D. K., Indraja, V., & Krishna, V. H. (2016). A review on small scale wind turbines. Renewable and Sustainable Energy Reviews, 56, 1351–1371. https://doi.org/10.1016/j.rser.2015.12.027
- UN (n.d.). About small island developing states | Office of the High Representative for the least developed Countries, landlocked Developing Countries and small island developing states. https://www.un.org/en/page/sids
- WEB. (n.d). WEB Aruba N.V. | Water- en Energiebedrijf Aruba N.V. Webaruba.com. https://webaruba.com

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Times fly when you have fun.

These eleven weeks in Aruba are coming to an end and I cannot believe how quickly it has gone. But it is definitely a good sign; times fly when you have fun (or when you have too much to do). I am leaving this island with new perspectives and memories for life.

Before coming here, I expected to learn about how to apply sustainability in a real-world setting since that is my field of study. However, this experience has taught me so much more than that. One of the most valuable parts of this has been the chance to not only live with but also meet and get to know so many different nationalities and cultures in such a short time. From the very beginning, the students and staff of the University of Aruba and other locals have made me feel so welcome on this island. It has been an amazing learning experience, where I have learned so much from my classmates simply through having conversations. Apart from sustainability, I've learned about post-colonial history, the complexities of society, and the important role language plays in shaping who we are, and I am especially thankful to learn about it through the eyes of Arubans.

Furthermore, I've learned even more about teamwork. Although I thought I had it figured out after almost three years in Global Sustainability Science, the consultancy project was a real test on how to collaborate on such an important and comprehensive topic. However, it is motivating to know that we are part of something that could make a real difference. I've also faced a new kind of dilemma; balancing the temptation of a sunny beach nearby with deadlines and meetings.

One of the things I will miss most about Aruba is driving around in our little red car, Manuelita. However, I can't decide what my favorite memory is; listening to music from the JBL speaker because the car stereo didn't work, the

clutch breaking and us pushing the car into the right parking spot or spending two hours at the gas station waiting for our car renter after the tire got flat. Besides that, the best part of this journey was living in the same place as all the other students. It's been amazing to always have someone to talk to, a door to knock on, and something happening. Sharing dinners with everyone, especially by the beach while watching the sunset, experiencing carnival, and eating pastechi's from the university cafeteria are memories I really appreciate. The experience would not have been the same without all the amazing people that I shared it with, and the (baby) goats <3. Thanks to my amazing roommate Sophie for making me laugh every day. And to Sophie, Kaja, and Gabriella for being supportive and inspiring friends but also generously giving me access to three extra wardrobes.

Aruba is an island with so much to discover. Some of the highlights have been hiking to the natural pool, swimming with beautiful fish and turtles and exploring hidden caves. Aruba made me reconnect with nature, the sound of wind and waves, the frequent rainbows, all kinds of animals. I love how the sun sets so peacefully on one side of the island, while the waves crash wildly on the other. Even though I've been here for a while, I still feel like there's so much more to explore. Hope to see you again, Aruba.

No Rain, No Grain? Exploring the Potential of Local Feed Production for Livestock in Aruba

Inger Rødnes

1. Introduction

"Smallholder farmers feed one-third of the world. This means that for small island states like those of the CARICOM region, any serious effort at enhancing food security must start with increasing local production and improving self-sufficiency" (Beckford & Campbell, 2013). One of the local food production methods in Aruba, an observer of the Caribbean Community (CARICOM) region, is animal husbandry. Animal husbandry, defined as "breeding, rearing, and caring for farm animals" (Collins Dictionary, n.d.), is embedded within Aruba's culture, such as traditions like the goat stew at Christmas. Beyond cultural significance, livestock plays a role in Aruba's food production sector, providing essential food products, such as meat, milk, and eggs, to local markets, hotels, restaurants, as well as shared within the farmer's community of friends and family. However, this sector faces a significant challenge: its substantial contribution to greenhouse gas (GHG) emissions, particularly methane (CH_4), originating from enteric fermentation and manure management (De Vries & De Boer, 2009). Globally, livestock accounts for roughly 15% of human-induced emissions, with agriculture contributing nearly half of that total (Hristov et al., 2013). A major driver of these emissions is feed production (Bhatt & Abbassi, 2021). In a climate-conscious world, the urgency to mitigate livestock emissions and minimize resource use demands innovative and sustainable solutions.

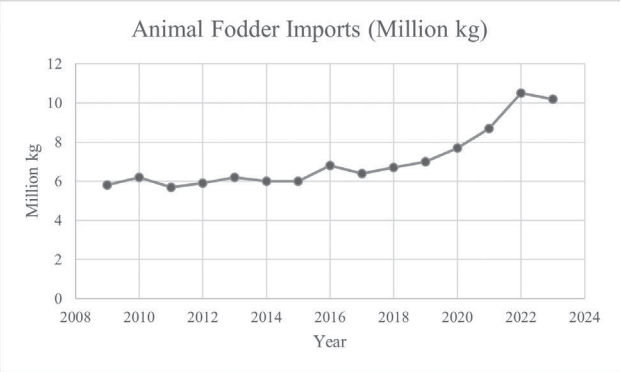

Figure 1: The change in imports of Prepared Animal Fodder to Aruba between 2009-2023 (CBS Aruba, 2024).

My research done in Aruba reveals a vulnerability in the current animal husbandry system on the island: the heavy reliance on imported animal feed. This not only amplifies transportation-related emissions but also exposes the island's food system to possible future risks from external shocks, as experienced during the Covid-19 pandemic, as well as former supply chain instabilities (Stanberry & Fletcher-Paul, 2024). As one of the Aruban respondents stated: "Being self-sufficient is very important" (Respondent 1, personal communication, 2025).

The steady increase in prepared animal fodder imports to Aruba, as evidenced by CBS Aruba (2024) and illustrated

in Figure 1, underscores this reliance. From 2009 to 2023, imports increased by approximately 75.86%, representing a 4.4 million kg increase. Notably, 2022 witnessed a dramatic 20.69% year-on-year spike, likely reflecting during- and post-Covid-19 agricultural expansion driven by heightened food security concerns and growing interest in local animal husbandry.

In addition to greenhouse gas emissions, animal husbandry presents other challenges that are particularly relevant to Aruba's climate. As a semi-arid island, Aruba receives only about 510 mm of annual rainfall and has just 10% arable land (Van der Burg et al., 2012). Research shows that the consumption of animal products accounts for approximately 27% of the global water footprint, compared to only 4% from domestic water use (Hoekstra, 2012). This is another critical challenge that cannot be overlooked and must be taken into account when considering animal feed production.

While optimizing livestock feed is crucial, it is essential to acknowledge that plant-based agriculture remains the most environmentally efficient food production method. Plant-based systems offer significantly higher nutritional yields per kilogram compared to animal husbandry, primarily due to the energy losses inherent in animal conversion processes (Bleukx et al., 2021). This inefficiency translates to a larger carbon footprint per unit of animal product.
However, recognizing the integral role of meat in Aruban culture, my research aims to explore sustainable pathways that maintain these cultural practices while minimizing environmental impact. Central to this paper is the research question:

How can locally available and potentially adaptable feed sources be optimized to reduce water consumption, land use, and methane emissions within Aruba's livestock sector?

This report examines sustainable feed options for cattle, goats, sheep, pigs, and chickens, with a focus on water-, land-, and methane-reducing alternatives, as well as circular economy approaches. It presents findings from quantitative and qualitative field research conducted in Aruba and evaluates the benefits, limitations, and risks of various feeding strategies, all within the island's unique environmental and socio-economic context.

2. Literature Review

2.1 Sustainable Farming Methods for Fodder Production

Limiting the land area used for livestock production is a crucial strategy for reducing its environmental impact. Steinfeld et al. (2006) highlight that livestock production accounts for about 80% of total agricultural land use. More efficient land-use practices can significantly lower its environmental footprint (Wirsenius et al., 2010).

This literature review explores various farming methods and considerations that optimize land use. In the following results section, findings on current livestock farming practices in Aruba will be presented, along with an exploratory analysis of alternative feed sources suitable for the region. To effectively produce these feed types, the farming strategies presented in the literature review provide directions for optimizing land use.

2.1.1 Cut-and-Carry System

The Cut-and-Carry system, which involves cutting forage and carrying it to livestock rather than allowing them to graze freely, is especially applicable to areas with land scarcity, such as Aruba. Furthermore, it is also currently in use in Aruba (Expert, personal communication, 2025). Controlled feeding in zero-grazing setups ensures that high-quality, locally grown feed is used optimally with lower excessive land use (Mtengeti et al., 2001).

2.1.2 Agroforestry and Intensive Fodder Gardens (IFG)

Figure 2: Illustration of how an Intensive Fodder Garden can look like (FAO, 1991).

Integrating agroforestry practices, particularly the planting of leguminous trees, offers a dual benefit: improved soil health and nutrient-rich fodder. These systems provide shade, reducing water evaporation and heat stress for plants. Establishing small-scale, high-yield intensive fodder gardens (IFG) with drought-resistant crops can reduce reliance on imported feed and maximize productivity in limited spaces. IFGs provide a stable and diverse diet rich in essential nutrients, which significantly enhances livestock productivity (FAO, 1991). Beyond direct nutritional benefits, IFGs also contribute to soil health and circularity. Incorporating nitrogen-fixing plants improves soil fertility, reducing the need for synthetic fertilizers. Another advantage of IFGs is their economic feasibility, as growing nutrient-rich grasses and fodder crops on-farm can be more cost-effective than purchasing commercial feed (Oridijoshua, 2025).

2.1.3 The Importance of Biodiversity

Figure 3: Illustration of what agroforestry practices can look like, with trees giving shade to other plants growing (FAO, 1991).

The increasing frequency and intensity of extreme climatic events underscore the critical role of on-farm biodiversity in enhancing agricultural resilience. As observed over the past two decades, farms with greater biodiversity exhibit a stronger capacity to withstand climate disasters (Altieri & Nicholls, 2013). Utilizing locally available knowledge and resources is crucial for preparing for potential risks related to climate change. Two international reports (IAASTD 2009; de Schutter 2010) recommend a shift to agroecology for enhanced food production to feed nine billion people by 2050. They suggest small-scale farmers can double output within a decade using existing agroecological methods.

2.2 Addressing Water Scarcity in Aruba's Feed Production

Aruba's extremely limited freshwater resources, primarily derived from desalination, pose a challenge for agriculture (Halman & Marchena, 2018; Knöfler et al., 2024). The absence of key nutrients in this water, compared to natural sources, necessitates careful water management strategies. Combined with the island's limited rainfall, reducing water consumption is a fundamental requirement for any sustainable animal husbandry system in Aruba. Prioritizing

drought-resistant feed crops minimizes irrigation needs. Implementing private rainwater harvesting and drip irrigation systems can further improve water-use efficiency in intensive fodder gardens (Ray & Majumder, 2024). Additionally, the use of treated wastewater for irrigation of non-human consumption fodder crops offers a sustainable water management strategy, provided that the wastewater undergoes appropriate treatment (Mishra et al., 2023).

2.3 The Importance of Circularity in Livestock Farming

Integrating circular principles into animal husbandry and feed production is essential for improving sustainability. One key aspect is the use of animal waste as a natural fertilizer for growing feed crops. Instead of relying on synthetic fertilizers, which are often imported and contribute to environmental pollution, manure can be repurposed to enrich the soil, enhance nutrient cycling, and improve crop yields. This approach reduces dependency on external inputs while closing the loop between livestock and agriculture (Bhagat et al., 2024). Additionally, by utilizing compostable waste streams, farms can further minimize waste, lower costs, and create a more self-sufficient system (Koul et al., 2021).

Utilizing residue and by-products, including local crop residues, brewery grains, and food waste from hotels/restaurants, can further reduce pressure on land and water resources while lowering emissions from decomposing organic matter. These techniques and systems are all currently in place in Aruba but can always be improved and be used more frequently (Respondent 3 & Respondent 4, personal communication, 2025). Making use of such circular strategies strengthens food security, reduces emissions associated with fertilizer production and transportation, and promotes healthier soil conditions, ultimately making animal farming in Aruba more resilient and sustainable.

3. Methods

This study employed a mixed-methods approach to investigate sustainable feed production for livestock in Aruba. Data collection was carried out through semi-structured interviews with local farmers and personal communication with an expert in local agricultural practices.

The interviews provided insights into current feeding practices, including reliance on imported feed and fertilizer use, and their perceptions on these aspects. This study includes a total of eight respondents, all of whom are either hobbyists, farmers, or taking care of animals in Aruba. Additional data on land requirements for cultivating feed like Pasto de Corte and Leucaena, as well as their growth characteristics and suitability for Aruba's conditions, were obtained from the expert. Information about available grazing space for goats and sheep and animal feed types present in Aruba, including buffer grass and sugarcane was also provided by the local expert.

A comparative analysis was conducted to evaluate the land requirements for different feeding systems, specifically grazing versus cut-and-carry. To ensure accuracy, data obtained from expert communication were validated against findings from relevant literature.

Furthermore, a literature review was conducted to explore sustainable feed production methods, with a focus on optimizing feed sources and reducing methane emissions. As no specific data on the environmental impact of alternative feeds in Aruba was available in existing studies, research from regions with similar semi-arid climates was used to provide the most realistic and applicable estimates. The literature review covered various feed sources, including different trees, crops, insects, and seaweed, assessing their potential to enhance sustainable livestock feed production in Aruba.

4. Results

The result section is divided into two parts, with the first one presenting on-site data from interviews carried out in Aruba. The second part is an explorative analysis of types of animal feed that can be or are already in use in Aruba, based on mostly literature review, and some data collected from the local expert.

4.1 Current Feeding Practices in Aruba

Table 1 presents the results obtained from eight different farms in Aruba. Seven out of eight respondents who kept animals in Aruba relied partially or entirely on imported feed. All respondents used manure as fertilizer, either on their own farms or by selling it to friends and family. Five out of eight used it to fertilize soil for food crops intended for human consumption, while two applied it to maintain grazing land for their animals. Only one respondent used fertilizer specifically for growing animal feed. The widespread use of manure as fertilizer demonstrates its role in nutrient cycling, although primarily used for food crops for human consumption rather than animal feed, this presents an opportunity to optimize local feed production. With only one respondent fertilizing land specifically for animal feed, there is significant potential to encourage more sustainable, locally produced fodder sources.

Table 1: Overview of where the animal feed origins and fertilizer use by manure for the respondents in this research.

Respondent	Feed source	Manure for fertilizer usage
1	Imports all	Food crops
2	Imports all	Food crops
3	Cut-and-Carry	Grazing land
4	Kitchen scraps, imports, grazing	Grazing land
5	Imports all	Food crops
6	Imports all	No data
7	Import, grazing, cut-and-carry	Food crops
8	Imports and cut-and-carry	Food crops and animal feed

Table 2 compares the land requirements for free-grazing animals versus those fed through a cut-and-carry system, as described in the literature review. According to Farmbrite (2025), a single cow requires 3.2 hectares if fully dependent on grazing, while goats and sheep typically need one hectare for every 3–4 animals (Expert, personal communication, 2025). The table illustrates that adopting a Cut-and-Carry system can reduce land use by a factor of 31 for cows and around 16 for goats and sheep, resulting in land savings of 97% and 94%, respectively. Even if considerable land is still used, this highlights the substantial benefits of keeping livestock in controlled environments and feeding them through Cut-and-Carry or IFG systems to optimize land use efficiency. To ensure animal welfare, it is essential to provide livestock with sufficient space. The "Beter Leven Keurmerk" certification can serve as a valuable reference for establishing appropriate living conditions (Beter Leven keurmerk, n.d.).

Table 2: Grazing animals relying solely on grazing versus a Cut-and-Carry system, where feed consists of Pasto de Corte grass supplemented with the drought-resistant, high-protein fodder plant Leucaena, and mineral and salt blocks.

Animal	Land area grazing (ha/animal)	Land area Cut and Carry (ha/animal)	Difference (ha/animal)	Percentage of land saved
Cow	3,2	0,102	31	97 %
Goat/Sheep	0,286	0,018	16	94%

Figure 4 illustrates the water and land use per kilogram of product for ruminants raised in Cut-and-Carry systems, as well as for pigs and chickens fed on kitchen scraps, utilizing fewer resources, highlighting the potential of waste-based feeding systems in reducing environmental impacts. The Cut-and-Carry system demonstrates significantly higher water use, and even with reduced land use compared to free-grazing, its land use remains greater than that of pigs and chickens.

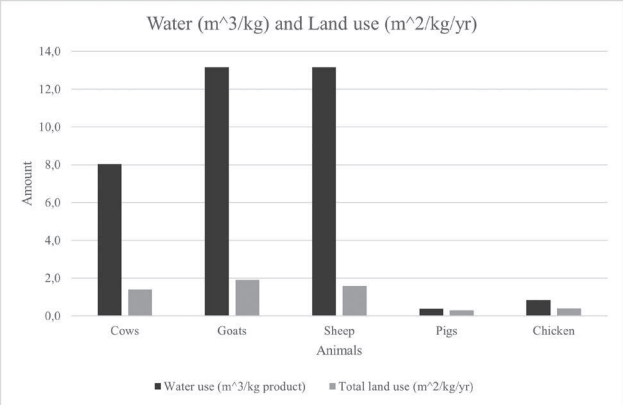

Figure 4: Water and land use of animals. Cows, goats and sheep fed in a Cut-and-Carry system, pigs and chicken fed on kitchen scraps and protein addition from Moringa trees.

Looking at the social impacts of importing animal feed, several respondents emphasized the economic challenges of livestock farming in Aruba, particularly the high costs associated with feed imports. One respondent highlighted the necessity of growing their own feed to ensure both profitability and sustainability:

"Yes, very sure, because the feed is very, very expensive. Because that's the big problem here, everything we have to buy is very expensive. We have to produce our own feed for the animals" (Respondent 4, personal communication, 2025).

Additionally, concerns were raised about the financial feasibility of feed production on the island. One respondent pointed out the benefits of self-production but also highlighted the significant expenses involved:

"Yeah, it's positive for us. To produce everything ourselves. The problem is, it's too expensive" (Respondent 7, personal communication, 2025).

These statements underscore the financial constraints faced by farmers in Aruba, suggesting that while self-production could offer long-term benefits, the costs involved may pose a barrier to widespread adoption.

4.2 An Explorative Analysis of Animal Feed Alternatives in Aruba

Optimizing feed sources, particularly by enhancing digestibility (Bhatt & Abbassi, 2021), emerges as a key strategy for sustainable livestock farming. Enhancements in feed utilization efficiency have the potential to optimize production outcomes and reduce methane (CH_4) emissions (Waghorn & Hegarty, 2011).

4.2.1 Trees

Firstly, trees play a vital role in agroforestry and intensive fodder garden (IFG) systems by providing shade and nutritious feed. Three drought-resistant trees with methane-reducing potential are presented below.

- Leucaena (Leucaena leucocephala): A protein-rich tree, Leucaena reduces methane emissions due to condensed tannins and bioactive compounds that inhibit rumen microbial activity (H. El-Zaiat et al., 2020; Tan et al., 2011; Stifkens et al., 2022; Montoya-Flores et al., 2020). It also enhances soil fertility by fixing nitrogen (Rahman et al., 2022).
- Moringa (Moringa oleifera): Moringa leaves are rich in protein and fibre, and studies suggest it can reduce methane emissions by altering the rumen microbiome (Elghandour et al., 2017). It provides a sustainable alternative to soybean meal (Su & Chen, 2020).
- Gliricidia (Gliricidia Sepium): This leguminous tree improves digestibility and reduces methane when added to low-quality diets (Zain, 2020). It offers high protein content but can be toxic to non-ruminants (Silopak, 2023).

4.2.2 Grass

In addition to trees, grasses are essential for livestock feed in Aruba. Two grass types currently used in Aruba for animal feed are included in this analysis (Expert, personal communication, 2025).

- Pasto de Corte (Elephant Grass - Pennisetum purpureum): This grass supports 50-100 sheep or goats per hectare with a cut-and-carry system. For cattle 5/6 times more space is needed (Expert, personal communication, 2025). It is well-suited for zero-grazing systems, especially in areas where land resources are limited (Mtengeti et al., 2001). Elephant grass serves as an effective base feed, supplements like leucaena are recommended to enhance nutrition (Expert, personal communication, 2025).
- Buffelgrass (Cenchrus ciliaris): Though less preferred by livestock, buffelgrass is highly drought-resistant, making it ideal for Aruba's semi-arid climate (Expert, personal communication, 2025).

4.2.3 Other feed types

Several alternative feed types hold promises for sustainable feed solutions in Aruba, with additional methane-reducing potential.

- Black Soldier Fly Larvae (Hermetia illucens): Studies show that including 4% black soldier fly larva oil in livestock diets can lower methane emissions while maintaining dry matter degradability (Hancz et al., 2024). Insect farming is also more land- and water-efficient than traditional livestock feed sources (Van Huis & Oonincx, 2017).
- Mealworms (Tenebrio molitor): Mealworm larvae are another sustainable protein source that can enhance growth rates and uptake of proteins in broiler chickens and pigs without negative effects (Hancz et al., 2024).
- Seaweed (Ulva lactuca): Locally available in Aruba, Ulva lactuca (Dutch Caribbean Species Register, n.d.), has moderate protein content, but its impact on methane reduction in livestock is still under research (El-Waziry et al., 2015). In poultry, however, it has shown positive effects on body weight gain (Alagan et al., 2020). Other seaweed species like Asparagopsis taxiformis have demonstrated significant methane reduction (Liu et al., 2024), however it is not suitable in Aruba since it is not a native species.
- Sugarcane Molasses (Saccharum officinarum): A readily available feed component in Aruba, sugarcane molasses can be combined with elephant grass to enhance its nutritional profile (Expert & Respondent 7, personal communication, 2025). However, it has limited protein content and is mainly used for energy.

Table 3 on the next page provides an overview of the feed types presented above, highlighting their key characteristics for clearer comparison and better understanding.

Feed Type	Category	Drought Resistance	Methane Reduction Potential	Nutritional Benefits	Limitations
Leucaena *(Leucaena leucocephala)*	Tree	High	Yes (Tannins, Bioactive Compounds)	High protein, Nitrogen-fixing	Potential toxicity if overfed
Moringa *(Moringa oleifera)*	Tree	High	Yes (Rumen microbiome changes)	High protein, Comparable to soybean	Contains saponins, slight bitterness
Gliricidia (*Gliricidia sepium)*	Tree	High	Yes	High protein, Increases digestibility	Toxic to non-ruminants
Elephant Grass (*Pennisetum purpureum)*	Grass	Moderate	Not specified	Sustainable fodder, Supports livestock	Requires supplements for optimal nutrition
Buffelgrass *(Cenchrus ciliaris)*	Grass	Very High	Not specified	Drought-resistant, Low maintenance	Less preferred by animals
Black Soldier Fly Larvae *(Hermetia illucens)*	Insect	N/A	Yes (Oil supplementation)	High protein, Sustainable	Requires specific farming conditions
Mealworms *(Tenebrio molitor)*	Insect	N/A	Not specified	High protein, Boosts growth efficiency	Processing required
Seaweed (*Ulva Lactuca)*	Algae	N/A	Uncertain (Species-dependent)	Moderate protein, Local availability	Needs more research on methane impact
Sugarcane Molasses (*Saccharum officinarum)*	By-product	N/A	Not specified	Energy-rich, Can be mixed with grasses	Limited protein content

Table 3: An overview of the alternative animal feed that can be produced in Aruba, and their characteristics including methane reduction potential, drought resistance, nutritional benefits and limitations.

5. Discussion

The aim of this paper was to investigate: "How can locally available and potentially adaptable feed sources be optimized to reduce water consumption, land use, and methane emissions within Aruba's livestock sector?".

The most significant challenge identified for increasing local animal feed production is the extensive water use. This is a downside both when it comes to Aruba-specific, due to the limited access to freshwater, but also when compared to plant-based diets, animal feed production generally requires substantially more water. While the plants and trees that were studied, such as Leucaena and Moringa have proven adaptability to Aruba's climate, their large-scale cultivation to meet livestock feed demands would significantly strain existing water resources. This would necessitate the implementation of efficient water management strategies, including rainwater harvesting, use of recycled water and drip irrigation, alongside the prioritization of drought-resistant species like buffelgrass. Furthermore, the limited land availability in Aruba presents another critical constraint, emphasizing the need for intensive and optimized land-use practices. Approaches like Cut-and-Carry systems, Intensive Fodder Gardens and agroforestry practices, as demonstrated by their land-saving potential, offer promising solutions for maximizing feed production within confined spaces. However, these systems require more water than free-range grazing, exacerbating the already significant water usage challenges in animal husbandry. And, as can be seen in Figure 4, they still require significant water and land use per kg product.

Additionally, the environmental benefits of reducing transport-related emissions through local feed production can only be realized if the crops are cultivated sustainably in Aruba. A life cycle assessment (LCA) by Lelièvre-Damit (2022) on chicken imports to Aruba found that the highest environmental impacts stem from the production process in the country of origin. This underscores the importance of incorporating sustainably grown animal fodder, such as methane-reducing crops, to ensure that local feed production not only enhances food security but also aligns with broader environmental sustainability goals.

Economic considerations also play a crucial role in a transition to sustainable feed production. Local farmers face economic challenges when buying imported feed, but also when producing crops locally. If Aruban animal farmers aim to commercialize animal husbandry, they may face challenges competing with the low prices of imported food available in local supermarkets. Implementing policy interventions such as taxes on imported animal feed and providing subsidies for local producers could benefit local production.

The current practice of utilizing manure as fertilizer demonstrates the applicability of circular agricultural practices. However, a shift in focus is required to prioritize fertilizer application for animal feed production, rather than only for human consumption crops, if locally grown feed is desired. To mitigate environmental impacts, the focus needs to be on methane-reducing crops and trees. This approach not only enhances feed efficiency but also contributes to reducing the livestock sector's carbon footprint.

Moreover, the importance of on-farm biodiversity and circularity needs to be highlighted. Promoting diverse crop and tree combinations, as well as integrating waste streams, such as recycled water and kitchen scraps, into the feed production cycle, strengthens the resilience of the livestock system and minimizes environmental impact.

It is important to note that implementing alternative feed strategies can pose several risks. Kitchen scrap use can lead to plastic and chemical contamination, necessitating strict waste separation and supplier education (Respondent 4, personal communication, 2025). Certain feed crops, like

Leucaena, can be toxic in high quantities, requiring careful rationing (Halliday et al., 2013). Additionally, introducing non-native species like Asparagopsis taxiformis for methane reduction should be avoided to protect local ecosystems, since this poses risk for invasiveness. Furthermore, a leguminous neem tree, Azadirachta indica, is an exotic species in the Caribbean, and if not managed well, invasiveness can occur, which further disrupts the ecosystems (Van der Burg et al., 2012).

However, the successful implementation of these strategies relies on farmer education and training. It is crucial to have the knowledge and skills to manage biodiversity effectively, including the proper combination of crops and the appropriate use of feed additives to avoid toxicity.

While optimizing feed can reduce the environmental impact of livestock farming, it is crucial to acknowledge that animal agriculture inherently produces high emissions. The most effective strategy for sustainability is reducing reliance on animal-based foods and shifting towards plant-based diets. However, for farmers committed to animal husbandry, implementing locally adapted, methane-reducing feed options is a valuable step as well.

Finally, while this paper provides explorative insights, it is important to acknowledge its limitations, particularly the small sample size and level of detail. Future research should aim to expand the sample size and extend the research done to enhance the quality of the findings.

6. Future research

While this paper explored various feed options, their specific effects on individual animal species and details about their detailed behaviour under Aruban conditions were not examined. For future research, investigate the effects of specific feed types on different livestock species to optimize nutrition and minimize emissions. Additionally, investigate the potential of sorghum, maize, and the tree Faidherbia albida in combination with sorghum, maize, or groundnut, and the native Aruban tree Watapana (Caesalpinia coriaria) for their water-efficient and methane-reducing properties (FAO, 1991; Jorge, 2025). Lastly, explore the feasibility of biogas production from animal manure through anaerobic digestion to create renewable energy and support circular economy principles (Ramos-Suárez et al., 2019; Tawfik et al., 2023).

7. Conclusion

While Aruba currently relies on imported feed to meet livestock needs, this approach is vulnerable to external disruptions and raises significant sustainability concerns. As livestock farming expands, locally sourced alternatives must be explored to enhance both food security and environmental resilience. Notably, given Aruba's limited water and land resources, and the substantial water use of animal feed, it is crucial to acknowledge and critically assess the long-term sustainability of the animal husbandry sector in itself.

However, the sustainability of this sector can be improved through targeted methods. For example, by a multi-strategy approach, combining locally grown crops, methane-reducing additives, and agricultural waste utilization, can ensure nutritional adequacy, reduce dependence on imports, and improve environmental performance. Incorporating a mix of tannin-rich legumes, drought-tolerant crops, and alternative protein sources offers a path toward reduced methane emissions and enhanced feed efficiency.

Feed options such as Leucaena, Moringa, and Gliricidia not only provide essential nutrients but also contribute to lowering methane production. Insects like black soldier fly larvae and mealworms, as well as seaweed supplements such as Ulva lactuca, show potential as protein-rich, low-emission feed components.

Looking ahead, future research should prioritize an optimal mix of Aruba-specific solutions, particularly drought-resistant, methane-reducing feed alternatives, and support the development of circular agricultural systems that close resource loops and build a more resilient, self-sufficient agricultural future for Aruba.

References

- Alagan, V. T., Vatsala, R. N., Sagadevan, I., Subbiah, V., & Ragothaman, V. (2020). Effect of dietary supplementation of seaweed (Ulva lactuca) and Azolla on growth performance, haematological and serum biochemical parameters of Aseel chicken. Beni-Suef University Journal of Basic and Applied Sciences, 9(1). https://doi.org/10.1186/s43088-020-00087-3
- Altieri, M. A., & Nicholls, C. I. (2013). The adaptation and mitigation potential of traditional agriculture in a changing climate. Climatic Change, 140(1), 33–45. https://doi.org/10.1007/s10584-013-0909-y
- Beckford, C. L., & Campbell, D. R. (2013). Food imports, domestic production, and food security in the Caribbean. In Palgrave Macmillan US eBooks (pp. 183–195). https://doi.org/10.1057/9781137296993_14
- Beter Leven keurmerk. (n.d.). Beter Leven Keurmerk. Retrieved, April 2nd 2025 from: https://beterleven.dierenbescherming.nl/
- Bhagat, R., Walia, S. S., Sharma, K., Singh, R., Singh, G., & Hossain, A. (2024). The integrated farming system is an environmentally friendly and cost-effective approach to the sustainability of agri-food systems in the modern era of the changing climate: A comprehensive review. Food and Energy Security, 13(1). https://doi.org/10.1002/fes3.534
- Bhatt, A., & Abbassi, B. (2021). Review of environmental performance of sheep farming using life cycle assessment. Journal of Cleaner Production, 293, 126192. https://doi.org/10.1016/j.jclepro.2021.126192
- Bleukx, K., Janssens, D., Vandenbergh, J. & Vankrunkelsven, E. (2021). Carbon 'Foodprint' of Aruba's Food Imports. Bachelor Dissertation. KU Leuven. https://hdl.handle.net/20.500.14473/1306
- CBS Aruba. (2024). Foreign Trade Tables (Import) 2000 – 2024. Retrieved from: https://cbs.aw/wp/index.php/2016/12/14/foreign-trade-tables-import/
- Co, F. (2001, August 9). Farmers perception of intensive

feed gardens: A case study of the Central and Lower River Divisions in The Gambia. http://www.lrrd.org/lrrd14/5/nwaf145.htm

- Collins Dictionary. (n.d). Definition of "animal husbandry". Collins Dictionary, HarperCollins Publishers. https://www.collinsdictionary.com/dictionary/english/animal-husbandry
- De Schutter O (2010) Report submitted by the Special Rapporteur on the right to food. UN General Assembly. Human Rights Council Sixteenth Session, Agenda item 3 A/HRC/16/49
- De Vries, M., & De Boer, I. (2009). Comparing environmental impacts for livestock products: A review of life cycle assessments. Livestock Science, 128(1–3), 1–11. https://doi.org/10.1016/j.livsci.2009.11.007
- Dutch Caribbean Species Register. (n.d.). https://www.dutchcaribbeanspecies.org/linnaeus_ng/app/views/species/nsr_taxon.php?id=182993
- Elghandour, M., Vallejo, L., Salem, A., Mellado, M., Camacho, L., Cipriano, M., Olafadehan, O., Olivares, J., & Rojas, S. (2017). Moringa oleifera leaf meal as an environmental friendly protein source for ruminants: Biomethane and carbon dioxide production, and fermentation characteristics. Journal of Cleaner Production, 165, 1229–1238. https://doi.org/10.1016/j.jclepro.2017.07.151
- El-Waziry, A., Al-Haidary, A., Okab, A., Samara, E., & Abdoun, K. (2015). Effect of dietary seaweed (Ulva lactuca) supplementation on growth performance of sheep and on in vitro gas production kinetics. TURKISH JOURNAL OF VETERINARY AND ANIMAL SCIENCES, 39, 81–86. https://doi.org/10.3906/vet-1403-82
- El-Zaiat, H., Kholif, A., Moharam, Attia, M., Abdalla, A., & Sallam, S. (2020). The ability of tanniniferous legumes to reduce methane production and enhance feed utilization in Barki rams: in vitro and in vivo evaluation. Small Ruminant Research, 193, 106259. https://doi.org/10.1016/j.smallrumres.2020.106259
- FAO. (n.d.) Using fodder from trees and shrubs to feed livestock in the tropics. https://www.fao.org/4/T1975E/T1975E04.htm
- Food and Agriculture Organization of the United Nations (FAO). (2019). GHG emissions by livestock: Trends and mitigation potential. FAO. https://www.fao.org/3/ca7089en/ca7089en.pdf
- Halliday, M. J., Padmanabha, J., Mcsweeney, C. S., Kerven, G., & Shelton, H. M. (2013). Leucaena toxicity: a new perspective on the most widely used forage tree legume. Tropical Grasslands - Forrajes Tropicales, 1(1), 1. https://doi.org/10.17138/tgft(1)1-11
- Halman, I. M., & Marchena, A. (2018). SEAWATER DESALINATION, THE SOLUTION FOR DRINKING WATER AUGMENTATION IN ARUBA FOR MORE THAN 85 yEARS: A HISTORICAL OVERVIEW DESALINIZACIÓN DE AGUA DE MAR, LA SOLUCIÓN PARA EL AUMENTO DE AGUA POTABLE EN ARUBA DESDE HACE MÁS DE 85 AñOS: UN PANORAMA HISTÓRICO. AQUA-LAC, 10(2). https://doi.org/10.29104/phi-2018-aqualac-v10-n2
- Hancz, C., Sultana, S., Nagy, Z., & Biró, J. (2024). The Role of Insects in Sustainable Animal feed Production for Environmentally Friendly agriculture: A review. Animals, 14(7), 1009. https://doi.org/10.3390/ani14071009
- Hoekstra, A. Y. (2012). The hidden water resource use behind meat and dairy. Animal Frontiers, 2(2), 3–8. https://doi.org/10.2527/af.2012-0038
- Hristov, A. N., Oh, J., Firkins, J. L., Dijkstra, J., Kebreab, E., Waghorn, G., ... & Tricarico, J. M. (2013). Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. Journal of Animal Science, 91(11), 5045-5069. https://doi.org/10.2527/jas.2013-6583
- IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development) (2009) Agriculture at a Crossroads. In: International

Assessment of Agricultural Knowledge, Science and Technology for Development Global Report, Island Press, Washington, D.C.

- Jorge. (2025, March 26). Plants - Watapana Tree - Caesalpinia Coriaria - Aruba Nature Adventure & Private Eco Tours Aruba. Aruba Nature Adventure & Private Eco Tours Aruba. https://arubaeco.tours/plants-watapana-tree-caesalpinia-coriaria_aruba_tours/
- Knöfler, Y. D.-M., Ramos-Monzón, M., Ståhlberg, S., Coelman, I., Rodriguez, Y. M., Negrini, G. (2024). Consultancy Report - The feasibility of rainwater harvesting systems in Aruba.
- Koul, B., Yakoob, M., & Shah, M. P. (2021). Agricultural waste management strategies for environmental sustainability. Environmental Research, 206, 112285. https://doi.org/10.1016/j.envres.2021.112285
- Lelièvre-Damit, J. (2022). Life cycle analysis of chicken in the Aruban food basket. Master dissertation. KU Leuven. https://repository.ua.aw/server/api/core/bitstreams/4b2318c7-a278-4ebf-a486-d5c37bbe05fe/content
- Liu, Y., Zhou, M., Diao, Q., Ma, T., & Tu, Y. (2024). Seaweed as a feed additive to mitigate enteric methane emissions in ruminants: Opportunities and challenges1. Journal of Integrative Agriculture. https://doi.org/10.1016/j.jia.2024.09.036
- Mishra, S., Kumar, R., & Kumar, M. (2023). Use of treated sewage or wastewater as an irrigation water for agricultural purposes- Environmental, health, and economic impacts. Total Environment Research Themes, 6, 100051. https://doi.org/10.1016/j.totert.2023.100051
- Montoya-Flores, M. D., Molina-Botero, I. C., Arango, J., Romano-Muñoz, J. L., Solorio-Sánchez, F. J., Aguilar-Pérez, C. F., & Ku-Vera, J. C. (2020). Effect of Dried Leaves of Leucaena leucocephala on Rumen Fermentation, Rumen Microbial Population, and Enteric Methane Production in Crossbred Heifers. Animals, 10(2), 300. https://doi.org/10.3390/ani10020300
- Mtengeti, E.J., Urio, N.A. & Mlay, G.D. (2001). Research note: Intensive fodder gardens for improving forage availability for smallholder dairy production in Hai district, Tanzania, Tropical Grasslands, 35, 124–127. https://www.tropicalgrasslands.info/public/journals/4/Historic/Tropical%20Grasslands%20Journal%20archive/PDFs/Vol_35_2001/Vol_35_02_01_pp124_127.pdf
- Oridijoshua. (2025, April 2). THE FUTURE OF LIVESTOCK FEED: HOW TO GROW NUTRIENT-RICH GRASS FOR MAXIMUM YIELD. - The Agricblog. The Agricblog. https://theagricblog.com/the-future-of-livestock-feed-how-to-grow-nutrient-rich-grass-for-maximum-yield/
- Rahman, M. M., Alam, M. S., Islam, M. M., Kamal, M. Z. U., Rahman, G. M., Haque, M. M., Miah, M. G., & Biswas, J. C. (2022). Potential of legume-based cropping systems for climate change adaptation and mitigation. In Elsevier eBooks (pp. 381–402). https://doi.org/10.1016/b978-0-323-85797-0.00030-6
- Ramos-Suárez, J., Ritter, A., González, J. M., & Pérez, A. C. (2019). Biogas from animal manure: A sustainable energy opportunity in the Canary Islands. Renewable and Sustainable Energy Reviews, 104, 137–150. https://doi.org/10.1016/j.rser.2019.01.025
- Ray, S., & Majumder, S. (2024). Water management in agriculture: Innovations for efficient irrigation (pp. 169–185). ISBN: 978-93-95700-90-0. https://www.researchgate.net/publication/381867727_Water_Management_in_Agriculture_Innovations_for_Efficient_Irrigation
- Silopak. (2023, July 30). Gliricidia tree fodder, high protein feed for ruminants. SILOPAK Silage Film and Bale Net Wrap. https://silopak.com/gliricidia-tree-fodder-high-protein-feed-for-ruminants/#:~:text=Gamal%20tree%20or%20in%20Latin%20Gliricidia%20sepium%20is,Asian%20

region.%20Especially%20in%20India%20and%20Sri%20Lanka.

- Stanberry, D., & Fletcher-Paul, L. (2024). Food availability in the Caribbean. In Palgrave studies in agricultural economics and food policy (pp. 93–133). https://doi.org/10.1007/978-3-031-66055-9_4
- Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & de Haan, C. (2006). Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations. https://www.researchgate.net/publication/239524071_Livestock's_Long_Shadow_Environmental_Issues_and_Options
- Stifkens, A., Matthews, E. M., McSweeney, C. S., & Charmley, E. (2022). Increasing the proportion of Leucaena leucocephala in hay-fed beef steers reduces methane yield. Animal Production Science, 62(7), 622–632. https://doi.org/10.1071/an21576
- Su, B., & Chen, X. (2020). Current Status and Potential of Moringa oleifera Leaf as an Alternative Protein Source for Animal Feeds. Frontiers in Veterinary Science, 7. https://doi.org/10.3389/fvets.2020.00053
- Tan, H., Sieo, C., Abdullah, N., Liang, J., Huang, X., & Ho, Y. (2011). Effects of condensed tannins from Leucaena on methane production, rumen fermentation and populations of methanogens and protozoa in vitro. Animal Feed Science and Technology, 169(3–4), 185–193. https://doi.org/10.1016/j.anifeedsci.2011.07.004
- Tawfik, A., Eraky, M., Osman, A. I., Ai, P., Zhou, Z., Meng, F., & Rooney, D. W. (2023). Bioenergy production from chicken manure: a review. Environmental Chemistry Letters, 21(5), 2707–2727. https://doi.org/10.1007/s10311-023-01618-x
- Van der Burg, W. J., De Freitas, J., Debrot, A. O., & Lotz, L. A. P. (2012). Naturalised and invasive alien plant species in the Caribbean Netherlands: status, distribution, threats, priorities and recommendations. PRI report, 437. https://edepot.wur.nl/198282
- Van Huis, A., & Oonincx, D. G. a. B. (2017). The environmental sustainability of insects as food and feed. A review. Agronomy for Sustainable Development, 37(5). https://doi.org/10.1007/s13593-017-0452-8
- Waghorn, G., & Hegarty, R. (2011). Lowering ruminant methane emissions through improved feed conversion efficiency. Animal Feed Science and Technology, 166–167, 291–301. https://doi.org/10.1016/j.anifeedsci.2011.04.019
- Wirsenius, S., Azar, C., & Berndes, G. (2010). How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agricultural Systems, 103(9), 621–638. https://doi.org/10.1016/j.agsy.2010.07.005
- Zain, M. (2020). Effects of Supplementing Gliricidia Sepium on Ration based Ammoniated Rice Straw in Ruminant Feed to Decrease Methane Gas Production and to Improve Nutrient Digestibility (In-Vitro). International Journal on Advanced Science, Engineering and Information Technology. https://www.academia.edu/93972988/Effects_of_Supplementing_Gliricidia_Sepium_on_Ration_based_Ammoniated_Rice_Straw_in_Ruminant_Feed_to_Decrease_Methane_Gas_Production_and_to_Improve_Nutrient_Digestibility_In_Vitro_

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Endless evenings of the most beautiful sunsets.

I honestly do not know where to start… Thinking about Aruba in the dark and stormy winter months leading up to our stay here made me appreciate this place long before ever having set foot on the island. Now, having lived here a while, I can only say that this appreciation has grown immensely. Aruba is much more than the sun, endless ocean, and palm trees I was dreaming of. It is a place filled with passionate and interesting people who love their home here in the Caribbean. Having been given a chance to work with such an engaged and diverse group of locals and ultimately giving back to the community that has always been so generous and helpful to us, is an experience I am very grateful for.

There have been few moments in my life where I have learned so much in such a short amount of time. Getting to know a new place, new people, and a whole new field of study was sometimes much, and always interesting. I left my comfort zone and at times surprised myself. Milking goats and doing farm work is not something I initially expected from a consultancy, but is what made the project so much more meaningful. Also, I realized baby goats are the cutest thing in the world. (it took everything I had to not secretly take one home)

Life here in Blue Village is never boring. It is a place to come home and go exploring from. Snorkelling with turtles, night swims at the beach after endless evenings of the most beautiful sunsets, picnics, and boating trips are only some of the lovely times Aruba had in store for us. Hectic days out were followed by chill nights in (with new friends, crêpes, and tier lists). The best thing: being able to live it all again the very next day. I'll never forget hiking around the west point and discovering a natural rainbow machine. Waves crashed onto the rocks creating a spray of water vapor caught by the afternoon sunlight. It was wonderful

and fleeting, like our stay on Aruba that is sadly coming to an end.

But what good times it was. I loved it. It was fun. It was hard work. I learned a lot. It has been an intensive 10 weeks together and I can only conclude by saying how proud I am of our group. Thanks guys, you inspired me lots!

Exploring the Current State and Future Viability of Animal Husbandry on Aruba

Ilvie Versteeg

1. Introduction

Developing a more robust and future-proof food system that aims to increase food security and independence for the Aruban population is key in the increasingly variable global environment in which Aruba operates. A heavy dependence on external systems for sustenance leaves Aruba vulnerable to any impacts disrupting supply chains to the island (Boyer et al., 2020). Efforts have been undertaken to increase development of Aruba's agricultural sector in multiple ways. This paper aims to examine the animal husbandry sector on the island. Currently, very limited literature on this topic exists for Aruba. This paper reports on research done to examine animal husbandry systems and their overall socio-environmental impacts. More importantly, this research aims to explore the current state of animal husbandry on Aruba; outline economic viability, practicability, and desirability of such systems for the Aruba of the future; and identifies a potential pathway forward.

The paper is structured as follows: First, the methodology of the research is presented. Second, the literature review explains relevant concepts and the study area. Next, the results will be presented in figures, tables, and through writing. These results will then be integrated and explored further in a discussion. Integrated in the discussion and substantiated in the final paragraph are conclusions, limitations, and future research recommendations.

2. Methodology

This paper builds on research done for a Consultancy Project by students from the Global Sustainability Science bachelor of Utrecht University, investigating sustainable food systems in terrestrial and marine ecosystems in Aruba. That Consultancy Project advises on four types of food production systems, namely soil-based agriculture, innovative agriculture, animal husbandry, and aquaculture. A large amount of data has been collected for that project utilizing, amongst other methods, a literature review, surveys, and interviews. The research in this paper adopts these methods and expands on that knowledge where necessary through additional literature review.

More specifically, the literature review was used to clarify assumptions and concepts that act as theoretical basis of future findings and discussion. First, additional general information on the importance of food independence for Aruba was assessed. Then, an outline on global information regarding agricultural production systems was included, followed by an environmental comparison of different types of agriculture with an emphasis on animal food production. The importance of land-use constraints of animal husbandry systems and for Aruba in general

was substantiated after. Finally, circular agriculture and economic aspects were clarified. For this literature review the search engine Google Scholar was utilized.

Next, surveys were conducted in the Aruban community in which attitudes towards food production techniques were assessed, as well as consumer demands and workforce interest. These surveys were done in-person at several supermarkets on the island. Questions were structured using a 5 point Likert scale. This scale was used as a scientifically validated manner in which the preferential way of behaving of respondents can be measured (Joshi et al., 2015). Attitudes can vary from strongly disagreeing to strongly agreeing. After collection, data was structured in excel and synthesized in graphs. For this paper the surveys were then used to analyse consumption demands, current perceptions, and desired future expansion methods regarding food consumption and food system development.

Next to that, semi-structured interviews were conducted. For this the same interview script was used to interview primary producers in all four food production systems included in the Consultancy Project. In this paper the responses of 6 animal farmers and 7 additional stakeholders were analysed. The interviews were transcribed and coded in NVIVO and categorised in the four general themes of the Consultancy Project research: economic impact, social impact, environmental impact, and policy. For the animal farmer interviews sub-coding was done inductively for the economic findings and deductively for the socio-cultural findings. Findings were then structured and presented in table 1 and 2, found below. These tables include the percentual prevalence of findings and attitudes found through the coding of the interviews. As seen in table 1 and 2, findings were made anonymous and linked to numbered interviews to increase clarity and validity. The non-farmer interviews were coded into the four general themes only, from which findings were produced directly.

3. Literature and Context Review

In this section the assumptions and concepts behind the research are explained on the basis of a literature review and a contextual analysis. This literature and context review includes environmental and social impacts of different farming systems as well as the socioeconomic factors shaping Aruba's current farming sector. A basic understanding of these concepts creates the foundation for understanding and interpreting the results and subsequent discussion.

3.1 Food (In)dependence

Aruba is characterized as being 'near total dependent' on imported food (Boyer et al., 2020), the island is highly reliant on external food supply chains. The vulnerabilities and challenges related to this dependence became evident during the COVID-19 pandemic. The pandemic threatened food security globally, first of all by causing supply-chain disruptions due to for example export restrictions and labour shortages; and secondly by increasing economic instability of households, causing a shift towards the consumption of cheaper and less nutritious diets (Laborde et al., 2020). In Aruba, both supply-chain disruptions and economic impacts were felt considerably. This led to the recognition of the vital importance to strengthen food security on Aruba and the creation of a strategy to develop the national agricultural sector to achieve this (Boyer et al., 2020). A primary producing sector that is free of any imports is crucial to achieve a self-sufficient and independent food supply system. This is especially interesting in the case of animal husbandry due to the necessary procurement of animal feed supply.

3.2 Animal Husbandry: A Socio-Environmental Perspective

Animal husbandry entails the keeping of animals on commercial farms, hobbyist lands, or backyards to produce

animal food products such as meat, eggs, and milk. The place of such animal proteins in people's diets is increasingly challenged. Not only do animal production systems go hand in hand with concerns for social justice, animal welfare, and food safety, they are also a driver of climate change, bringing about a wide range of ethical, social, and political considerations (Gjerris et al, 2011). Animal agriculture is responsible for 16.5% of all greenhouse gas emissions globally (Twine, 2021). When compared to alternative food production systems, data shows that consumption of animal protein overall is more water, energy, and land-use intensive compared to plant-based alternatives (Mekonnen & Hoekstra, 2012; Poore & Nemecek, 2018; Nijdam et al., 2012; González et al., 2011). Additional consideration should be given to other harmful effects of animal husbandry systems, such as biodiversity loss (Nijdam et al., 2012). To summarize, animal food production is relatively inefficient in producing nutritional value and polluting. This should be taken into account in the aimed future development and expansion of Aruba's agricultural sector.

3.3 Land-Use Constraints

Keeping in mind land-use intensity of animal husbandry systems is crucial on Aruba due to serious land availability constraints and land competition. Literature shows that the minimum land requirement per person for food production ranges from 0.18 ha in diets excluding meat to 0.86 ha in diets including 381g meat per day (Peters et al., 2007). Using this data would mean that theoretically, if the entirety of Aruba would be used for agriculture and diets would not contain any meat, the island could sustain roughly 100,000 people. Providing complete sustenance for its estimated population of 110,000 inhabitants (CBS, 2023) is an impossible task. It should therefore be understood that complete food independence is an impossible feat for Aruba. This does not mean Aruba cannot strive to be as sustainable and independent as possible.

Furthermore, choosing to develop land for agricultural purposes would compete with space for nature or any form of urban development. Regulations on land-use changes on Aruba can be found in the Spatial Development Plan (Directie Infrastructuur & Planning, 2019). This plan describes "Countryside" lands as designated for either agriculture or sprawled build-up, placing the two in direct land-use competition. Additionally, important ecological areas are categorised as fit for development, increasing competition with nature and natural environments. From a biodiversity perspective, free-grazing of goats and other animals have especially large impacts on the Aruban environment (Blom, 2024). With half of the island already designated for either urban development or Arikok national park (Jurgens et al., 2024) there is roughly 90 km^2 or Aruba left about which land-use decisions can be made. These are crucial considerations for developing future agricultural systems.

3.4 Circularity & Economic Assessment

One approach to farming that promotes efficient management of resources and sustainability is circular agriculture, which holds great potential for animal husbandry. Aiming to balance population demands and producing healthy diets whilst keeping in mind economic and natural resource-efficiency, circular agriculture encompasses a move towards systems optimizing resource-use, minimizing waste, and practicing responsible land management (Rodino et al., 2023). Its goal is to create a closed-loop farming system that is regenerative and potentially restorative. Examples of circular practices in agriculture include: redirecting waste streams, for example for fertilizer creation; using waste streams from own and external sources, for example as feed; and improving or regenerating natural resources. Circular agriculture is interesting in the Aruban context because it reduces external inputs into the food production system. This would in this case translate to an independence from imports, and redirecting on-island resources to support

animal husbandry systems. From a monetary perspective, circular agriculture could prove interesting too. Feed inputs on average make up a significant portion of total production costs on animal farms, with percentages as high as 52% (USDA, 2015). Feeding animals on waste streams, which are likely cheaper or free-of-charge, would significantly lower costs and increase profitability of the farm.

4. Findings

4.1 Surveys

As explained in the methods, a total of 50 surveys were conducted in-person with the Aruban community. The surveyed group consisted of 6 individuals identifying as 'temporary residents' and 44 individuals identifying as 'Aruban'. Short-term visitors were not included in the survey. The respondent group can be considered relatively diverse, with occupational fields including for example: tourism, education, manual labour, government officials, horeca, food production, student, retired, and pastor. For this paper the questions regarding current perceptions on local food (Figure 1) and preferred methods to use for food production expansion (Figure 2) have been synthesized in two graphs.

When considering the current availability of local foods in Aruban supermarkets, over half of the respondents replied noticing 'very little' and a significant portion of respondents noticed 'some'. A small portion of respondents noticed 'none', contrary to a similar small amount of respondents noticing 'a lot'. Not a single respondent was recorded giving the most agreeing answer. When asked about the preferred methods for future food production expansion for Aruba, the smallest number of respondents (19%) prefers expanding animal husbandry. Most respondents expressed a preference for expanding soil-based agriculture (28%) or innovative agriculture (32%). When answering this question, giving multiple answers was possible but not required.

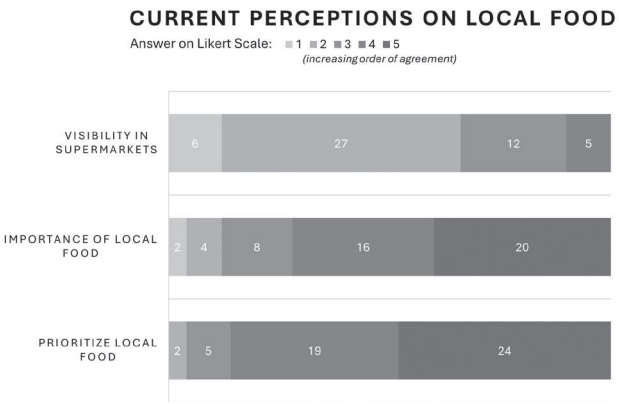

Figure 1: Survey results to questions regarding current perceptions of local food. Single-answer only, ordered using 5-point Likert scale.

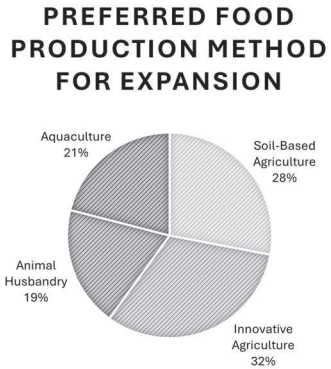

Figure 2: survey results to question: 'What food production processes do you believe are most likely to be successfully implemented on the island?'. Multiple answers possible.

4.2 Interviews

The interviews used in this paper were initially conducted for the Consultancy Project, and provide additional information regarding social, environmental, and economic aspects of animal husbandry systems, as well as local

opinions and recommendations regarding food production development for Aruba. 6 interviews with animal farmers and 7 interviews with additional stakeholders, including government departments, experts, and relevant organisations, were analysed. To ensure anonymity of interviewees, the interviews are labelled numerically as Interview 1 (I1) to Interview 13 (I13).

The tables below represent the input of the interviewees on economic aspects of current husbandry projects on Aruba (Table 1), and of general agreements and future aims of animal farmers (Table 2). Findings show that most animal husbandry farms were not profitable at the time of interviewing (I1, I4, I5, & I6), although two were considered commercial (I1 & I3). Additional analysis shows that engaging in animal husbandry is seen by most farmers as a passion project or as a continuation of family traditions (I2, I3, I4, I5, & I6). The findings demonstrate a general ambition among the interviewees to engage with animal husbandry, both at the household and hobbyist/commercial level. Animal husbandry is seen by all farmers as a challenging line of work and no farmer interviewed currently notices considerable input of their farm for Aruban food security. Half the interviewed group, including all farmers classify themselves as commercial, aim to contribute to food security in the future (I1, I2, & I3). Lastly, issues with increasing urbanization of Aruba, such as dog attacks or traffic accidents killing livestock and animal theft were identified as a problem by most animal farmers (I3, I4, I5, & I6).

Economic Findings	**Prevalence**	**Interview**
Describe their farm as profitable	17%	*I3*
Describe their farm as not profitable or a financial drain	67%	*I1, I4, I5, & I6*
Describe themselves as hobbyist or are non-commercial	67%	*I2, I4, I5, & I6*
Currently needs imports in feed mix to sustain farm	83%	*I1, I2, I3, I5, & I6*
Solely relies on imports for feed	50%	*I1, I2, & I6*

Table 1: Economic Findings of animal farming interviews including percentual prevalence of statements

Socio-Cultural Findings	**Prevalence**	**Interview**
Describe being an animal farmer as *'difficult'* or *'hard work'*	100%	*I1, I2, I3, I4, I5, & I6*
Describe their reason for practicing animal farming is '*passion'* or '*family tradition'*	83%	*I2, I3, I4, I5, & I6*
Describes climatic conditions as challenging or not ideal	67%	*I2, I3, I5, & I6*
Describe dog attacks or general urbanization as a problem	67%	*I3, I4, I5, & I6*
Aims for future impact on food security on the island	50%	*I1, I2, & I3*
Believes they currently impact food security on the island	0%	-

Table 2: Socio-Cultural findings of animal farmer interviews including percentual prevalence of statements

Stakeholder interviews provided additional insights regarding the economic, social, and environmental aspects of the issues addressed in this research. Considering the price and economic viability of animal husbandry systems, opinions differed. Several interviewees expressed economic challenges and drawbacks of animal farming, which for example resulted in letting grazers roam freely in order to reduce feed costs (I9 & I11), and local meat prices being unlikely to ever compete with imports (I13). Another stakeholder recognized economic benefits of on-island animal food production due to the absence of import tax and reduced sales tax (I10). A sentiment heard amongst several stakeholders was the necessity of general agricultural expansion on Aruba for economic diversification and the creation of a second income pillar for the island (I8, I10, & I11). None of the additional stakeholders interviewed challenged the need for agricultural development in the broadest sense in their interview.

The non-farming stakeholders interviewed echo the challenging relationship between animal husbandry and increasing urbanization of Aruba. This group of interviewees viewed such issues more external to the husbandry system, emphasizing the negative impacts of animal production systems on areas and ecosystems surrounding farms. This is exemplified in the concern of harmful environmental and community effects of free-roaming practices for grazers coupled with human population increase and land availability constraints (I7, I8, & I9).

Expert opinions on the direction of future expansion for animal husbandry systems emphasized potentials for circular farming with feed from side streams (I12 & I13) , but recognized the limitations of such systems for commercial farms due to sanitary and scalability constraints (I12 & I13). The size of future farms is up for debate too, with one stakeholder emphasizing the need of larger, more centralized systems for increased economic feasibility and professionalization (I13). Another stakeholder explains that the land constraints on Aruba make it impossible to set up such larger farms (I8). A lack of general legislation and sufficient quality controls (I7, I8, I9, I11, & I13) are identified as a general restriction to effectively develop and manage a future sustainable animal husbandry sector.

5. Discussion and Conclusions

This paper outlines relevant literature and connects it to community perceptions on food production, farmer perspectives, and other relevant stakeholder inputs. This allows for a preliminary assessment of the current state of the Aruban animal husbandry sector as well as an exploration of future recommendations and limitations.

During and after the COVID-19 pandemic, some government efforts and societal changes have pushed agricultural expansion and the importance of locally produced food to the forefront. All non-farmer stakeholders interviewed recognized the need to develop the agricultural sector for food security reasons, and some mentioned economic diversification as important too. These statements were made regarding the Aruban agricultural sector as a whole. Overall, stakeholders recognized specific challenges connected with animal agriculture that did not overlap with other agricultural production methods. This can be connected to the survey results stating that the Aruban community considers local food important and prioritizes buying local food over imported food. This is true even though relatively low levels of locally produced foods were visible in supermarkets. The same group of respondents that indicated a community demand for local foods found animal husbandry the least suitable method of food production for agricultural expansion on Aruba. This poses the question if animal husbandry is realistically a promising or desired pathway to follow.

Diving more into the specifics of animal husbandry from a non-farmer perspective, several challenges were identified.

In literature, the environmental impacts, including high greenhouse gas emissions, water-, and energy-intensity, and significant land-use pressures of animal husbandry were introduced. Of these, land-use competition and development have been identified as the most relevant factors impacting agricultural expansion on Aruba. Non-farmer interviews support this literature, with some stakeholders expressing general concern regarding environmental impacts, and most being concerned about land-use impacts. The most pressing issues identified are traditional free-roaming practices of grazers causing negative effects in the form of overgrazing and subsequent ecosystem degradation, and overall limited land availability. The grazing issue could arguably be solved by keeping grazers in gated systems. However, as two interviewees remarked, this would require feed provision by farmers who can not afford the high costs related to this. From these results it could be concluded that these animal husbandry systems with grazing animals are not the most suitable or sustainable way to raise animals on Aruba.

Assessment of insights from non-farmer stakeholders regarding economic viability showed that locally produced food could provide tax benefits over imports, for example through lower total sales tax when buying products directly from producers. This benefit is true for imported food as a whole and not animal husbandry-specific. On the other hand, high feed prices make economic feasibility of animal farming improbable, and locally produced meats are unlikely to ever compete with import, as one interviewee explains. Based on these findings, it could so-far be argued that animal husbandry might not be the most practicable or profitable in the Aruban context.

Feasibility aside, from a farmer perspective, animal husbandry can be considered a beloved way of practicing agriculture. Almost all farmers interviewed have a passion for this method of farming or were motivated to keep a family tradition going. Willingness to work is an important factor to successfully develop a sector, especially one that is dependent on independent workers or entrepreneurs like the Aruban agricultural sector. This sentiment is reflected in the finding that all commercial farmers interviewed aim to upscale their farm to significantly contribute to food security in the future.

However, when questioned about the practicalities of animal husbandry on Aruba, a less promising scenario is sketched. Over half of the animal farmers describe Aruban climatic conditions as not ideal. Additionally, the same number of farmers expressed difficulties with increased urbanization resulting in livestock death from traffic or theft. From an economic perspective, most farmers interviewed currently do not make any profits from farming. This includes one farmer that describes himself as commercial, and thus has profit as a target. Additionally, all but one farmer interviewed require imported feed to sustain their farm, and half rely on imports only. This makes the current animal husbandry sector highly reliant on external supply chains. It can then be concluded that due to this high reliance on imports, the animal husbandry sector with its current parameters, even if significantly expanded, does not contribute to food independence for Aruba.

Because of both economic and socio-environmental reasons, developing the Aruban animal husbandry sector can be considered sufficiently challenging. However, because of high willingness to work and the perceived cultural tradition of grazing husbandry, this paper explores a potential development strategy: circular agriculture in closed systems. Literature shows that circular agriculture aims to address the environmental and land-use issues addressed in this research through optimizing resource-use, minimizing waste, and practicing responsible land management. Circular practices on Aruba additionally hold the potential to diminish import-dependence of animal husbandry systems though feed from waste streams, likely providing economic benefits too. One stakeholder

interviewed explained the benefits of using circular side streams as feed stating:

"From that [imported] feed, the animal makes high-value proteins that then people eat, but there is a lot of energy and proteins that go lost. So raising animals is a good idea if you can raise them on a side stream, if you can raise them on something that we as people don't eat." (I12). Through decreasing feed costs the viability of keeping grazers in contained systems, formerly mentioned as economic constraint, increases.

Complications identified related to using waste streams as feed stem from scalability and sanitary concerns. It is currently unclear exactly how many animals can be fed from household, restaurant, business, and hotel food scraps. However, considering the size of certain businesses and the number of people consuming and wasting food on the island there is reason to assume several animal husbandry systems could be supported this way. Building animal husbandry systems around waste streams ensures that the animal husbandry sector would be reliant on the tourism sector. This arguably diminishes food independence due to the required 'import' of tourists to create the needed waste streams to feed animals with. An assessment of quantity and quality, as well as reliability of supply would be necessary to substantiate any claims. A lack of professionalization and quality control of side streams for feed are legitimate reasons for concern and could have harmful effects on animal husbandry systems and end product quality. For this system to work it is therefore advisable to create clear policies and quality assurance procedures.

Overall, animal husbandry on Aruba currently does not meaningfully contribute to food independence and arguably cannot be considered the most suitable agricultural sector to develop when having food security in mind. Comparison with plant-based agricultural systems on Aruba is needed to identify the most fitting way forward. One pathway to be explored further is circular agriculture which, if done mindfully, could provide some self-sufficient animal food production systems. The actual size of a circular agriculture system's contribution to overall food security for Aruba cannot currently be quantified, but based on the input from the local stakeholders there is reason to doubt substantial contributions from this approach.

References

- Blom, E. A. (2024). Herding Profits: Factors affecting Goat Commercialization amidst Grazing Constraints in Aruba.In Mijts, E. & Ballyne, J. UAUCU Student Research Exchange Collected Papers 2024. https://students.uu.nl/sites/default/files/BOOK%20LAY-OUT%202024%20web-mail%20versie.pdf
- Boyer, M. et al., 2024. Building Resilience in Aruba's Food Security During the Pandemic and Beyond (English), World Bank Group. United States of America. Retrieved from https://coilink.org/20.500.12592/353wlak on 04 Apr 2025. COI: 20.500.12592/353wlak
- CBS. (2023). The development of the population of Aruba. https://cbs.aw/wp/index.php/2022/11/24/test-births/
- Directie Infrastructuur & Planning. (2019). Ruimtelijk Ontwikkelingsplan Aruba 2019. https://www.dip.aw/wp-content/uploads/2021/06/20190722-ROP-2019-definitief-1.pdf
- Gjerris, M., Gamborg, C., Röcklinsberg, H., & Anthony, R. (2011). The Price of Responsibility: Ethics of Animal Husbandry in a Time of Climate Change. Journal of Agricultural and Environmental Ethics, 24(4), 331–350. https://doi.org/10.1007/s1080601092706
- González, A. D., Frostell, B., & Carlsson-Kanyama, A. (2011). Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation. Food Policy, 36(5), 562–570. https://doi.org/10.1016/j.foodpol.2011.07.003
- Joshi, A., Kale, S., Chandel, S., & Pal, D. (2015). Likert Scale: Explored and Explained. British Journal of Applied Science & Technology, 7, 396–403. https://doi.org/10.9734/BJAST/2015/14975
- Jurgens, S. S., Mijts, E., & Van Rompaey, A. (2024). Are there limits to growth of tourism on the Caribbean islands? Case-study Aruba. Frontiers in Sustainable Tourism, 3. https://doi.org/10.3389/frsut.2024.1292383
- Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID19 risks to global food security. Science, 369(6503), 500–502. https://doi.org/10.1126/science.abc4765
- Mekonnen, M. M., & Hoekstra, A. Y. (2012). A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems, 15(3), 401–415. https://doi.org/10.1007/s1002101195178
- Nijdam, D., Rood, T., & Westhoek, H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy, 37(6), 760–770. https://doi.org/10.1016/j.foodpol.2012.08.002
- Peters, C. J., Wilkins, J. L., & Fick, G. W. (2007). Testing a complete diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: The New York State example. Renewable Agriculture and Food Systems, 22(2), 145153. Cambridge Core. https://doi.org/10.1017/S1742170507001767
- Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987–992. https://doi.org/10.1126/science.aaq0216
- Rodino, S., Pop, R., Sterie, C., Giuca, A., & Dumitru, E. (2023). Developing an Evaluation Framework for Circular Agriculture: A Pathway to Sustainable Farming. Agriculture, 13(11). https://doi.org/10.3390/agriculture13112047
- Twine, R. (2021). Emissions from Animal Agriculture—16.5% Is the New Minimum Figure. Sustainability, 13(11). https://doi.org/10.3390/su13116276
- USDA. (2015, June 19). Composition of Production Expenses varies by Farm Commodity Specialization. https://www.ers.usda.gov/data-products/charts-of-note/chart-detail?chartId=78283

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Maybe one day, who knows, I'll have to come back.

I come from an island, one that taught me to live within limits, even before I understood what that meant. I grew up in the Canary Islands, and from a young age, I believed that staying was not an option. That to grow, I had to go. So I did. I find that ironic now. That this desire to leave is what brought me to Aruba: another island, another set of limits. But it's here, as an outsider, that I learned what it truly means to be an islander. The sea here taught me more than I expected. I gave myself the chance to dive, to get certified, to see the corals and the turtles. And somewhere underwater, I remembered who I was. I fell back in love with what I study. I fell back in love with the sea. To speak the island language is to share a "secret" with those who understand what it means to live with limits and maybe, for the first time, I finally understood that secret too.

I wouldn't have made it without the people beside me. Kaja, Inger, Sophie, they weren't just part of this trip, they were part of the shift. We were a little messy, a little loud, a little tired, and completely in it together. Us and Manuelita, our little red car that sounded like it was going to die every time we turned the key. But it didn't. Like us, it kept going. Somehow.

We drove around the island blasting Bad Bunny on the speaker, singing like no one was listening, and dancing a few too many nights at Kalibra. And between interviews and readings, there were goats to feed, trees to measure, mornings helping out at the shelter, afternoons hikes and days cooking traditional food. The dinners and beers together, the sunsets at the beach and all the late nights swimming. We lived a lot in a very short time.

And through it all, Aruba was teaching us. In the way people spoke to us, shared with us. We weren't just seen as outsiders passing through. Local Fishermen, Eric, Anita,

students at UA, Nathalie, NGOs and farmers: they all took the time to speak, to listen, to explain. They shared not just their work, but their experiences, their perspectives, their lives, their trust. That generosity stayed with us; it made us feel part of something real.

I came here thinking I was researching food systems, but I was also researching myself. The island gave me more than just data or interviews: it gave me clarity. And yes, we cried together a lot. And I was stressed. But now, writing, I can say with everything in me: it was worth it. I owe this island something I don't quite know how to repay. I owe the people, the conversations, the chaos, and the quiet moments. I owe my friends. I even owe that red car.

Maybe one day, who knows, I'll have to come back; not just to visit, but to give something back.

The Ocean Is Not Neutral: A Paper That Listens to Fishers and Contests Marine Governance in Aruba

Gabriela López Valle

1. Introduction

The sea has never belonged to one person alone. It has been a road, a source of food, a place for worship, and a distant line that held the promise of something more. To fishermen, it has been home. To tourists, a playground. To conservationists, a fragile world in need of protection. And yet, despite its vastness, the ocean is shrinking: not in size, but in access.

In Aruba, where the sea shapes both identity and economy, its use has become increasingly contested. As Marine Protected Areas (MPAs) move forward and management frameworks slowly begin to take form, artisanal fishers, who have depended on the sea for generations, are often excluded from waters they once freely navigated. Meanwhile, jet skis go through coral zones, cruise ships dock in once-quiet bays, and high-end resorts multiply across privatized coastlines. The sea, which once gave equally to all, is now being claimed, zoned, and sold.

This paper is not about market failures in the classical economic sense. It does not dwell on the "tragedy of the commons" as framed by Hardin (1968), which has long been commented on for ignoring the role of community governance, cultural values, and historical ties to place (Partelow et al., 2019). Hardin's model imagines a common stripped of social complexity, where rational self-interest leads to inevitable collapse. But in places like Aruba, the issue is not just overuse: it is erasure. A forgetting of who the sea has been for, and who gets pushed aside when new claims are made on old spaces.

Rather than a simple matter of efficiency, ocean governance in Aruba reveals a more profound tension between ecological conservation, economic development, and social justice. MPAs, while key for biodiversity, can reproduce inequality if they are not rooted in local realities and participatory governance (Jentoft et al., 2007). Schlüter et al. (2020) argue that ocean privatization, in the form of property rights, zoning, or exclusive use, must be evaluated not only through economic metrics, but also in terms of justice, inclusion, and long-term impacts on social-ecological resilience.

Privatization may promise order, growth, or efficiency, but it also brings risks: exclusion, disconnection, and irreversible change. The question, then, is not only what is gained, but what might be lost. Is Aruba prepared to take that risk, and who bears the cost if it goes wrong?

As a student of sustainability, with a focus on business and innovation, I have come to believe that solutions must begin with people. The ones living by the sea, feeding their families from it, naming its winds and currents. My work here is shaped not by clear models, but by conversations—open, generous, and sometimes difficult—with fishers, farmers,

NGO representatives, government actors, and community members. Their stories remind us that governance is not just about managing resources, but about honoring relationships. This paper, in many ways, is about that.

In Aruba, the people are still here. Older fishers speak of a time when the coastline was full of caracoles and lobsters. Now, they speak of permits they were never consulted about, of MPAs chosen without their input, mapped without their knowledge, of sons and daughters who would not follow their path because there is no path left to follow. And yet, there is still pride in their voices. Pride, and pain.

This essay is about them.

It is about the ocean as culture, memory, survival, and resistance. It is about how sustainability, if not rooted in justice, can become another form of dispossession. It asks hard questions: Who protects the protectors? Who speaks for those who cannot afford a voice in policymaking rooms? If the sea is to be saved, can it be done by silencing those who have lived with it the longest?

This paper is not neutral, because the ocean is not neutral. It holds stories. It holds pain. It holds possibility. And so does this research.

It asks: **How do fishers in Aruba experience and navigate marine governance policies, including restrictions on species, fishing methods, and access to marine spaces, and what does this reveal about participation, justice, and sustainability in small-island contexts?**

2. Methodology

This research is grounded in a qualitative approach rooted in fieldwork conducted over ten weeks on the island of Aruba. The core of the methodology consists of eleven semi-structured interviews with key stakeholders (Table 1), including small-scale fishers, representatives from non-governmental organizations (NGOs), actors from various governmental departments involved in marine management and conservation, business actors from different companies and a scientific expert.

Table 1 I Overview of Interview Participants by Type

Stakeholder type		Nº of participants
Small-scale fishers	Full-time	2
	Part-time	3
Government actors		3
NGO representatives		3
Business actors		2
Scientific experts		1

These interviews were conducted in both English and Spanish, depending on the comfort and preference of the participant. Conversations took place in informal settings: near docks, in offices, during site visits, in restaurants, or corners of different cafes. This flexibility allowed the interviews to unfold naturally, giving space for emotion, memory, and critique. Participants spoke not just of policies, but of frustration, hope, and everyday negotiation with systems that are often distant from their lived realities. All interviews were audio recorded (with consent), transcribed, and organized using NVivo software. Rather than coding thematically, the transcripts were carefully read and annotated to identify recurring quotes, tensions, and patterns across different stakeholder perspectives. This supported a grounded and systematic approach guided by direct engagement with participants' words.

Due to the sensitivity of the topics discussed and the closeness of the community, anonymity was a central ethical consideration. No identifying information is included in this paper, and care has been taken not to inadvertently

disclose affiliations or locations that could compromise privacy. In small island contexts, confidentiality is not simply a research requirement, it is a form of respect. In addition to interviews, I engaged in participant observation. I visited landing sites and fish markets, diving on the ocean, saw tourism and recreational activity in marine zones, and accompanied stakeholders on coastal visits and meetings. These encounters provided insight into how policy and marine use materialize on the ground and in the water. I paid attention to the unspoken as much as the spoken: body language, silences, tensions, and the ways people navigated space and systems.

This fieldwork was complemented by a review of policy documents, environmental assessments, and regional reports related to marine zoning, conservation, and tourism. Rather than acting as a passive context, these materials helped situate the interview insights within the larger structures that shape access to the sea. Relevant academic literature on ocean governance, privatization, and justice was also integrated into the analysis, particularly in the findings section, to help interpret and situate participants' experiences within broader theoretical and regional conversations. Ultimately, this methodology is not extractive, it is relational. It emerged through presence, listening, and reflection. It values local knowledge not as supplementary, but as central. While this research is limited in scope and time, it aims to amplify voices that are too often spoken for or overlooked. These stories do not offer clear solutions, but they offer truths that need to be heard.

3. Findings

3.1 The Sea as Livelihood, Identity, and Memory

This section begins with how fishers relate to the sea not just as a workplace, but as a source of identity, memory, and belonging. Their reflections reveal a deep, lived knowledge—one shaped by family, freedom, and changing conditions, and increasingly challenged by new regulations and shifting values.

3.1.1 Fishing as Knowledge, Freedom, and Tradition

Fishing in Aruba is not only an economic practice: it is a way of life. It carries knowledge, memory, and identity across generations. One fisher described it simply: "My grandfather was a fisherman. All my family were fishermen. I started fishing with him when I was six." Others recalled learning through immersion: "You used to snorkel in front of the boat, looking for bait. That's how we learned." These are not nostalgic stories. These are ways of knowing: embodied, practiced, and deeply rooted in place.

This knowledge does not sit in reports or zoning plans. It lives in the body and in how one reads the wind, the current, and the birds. "You watch the birds. They'll show you where the fish are," a fisherman told me. For many, fishing is not just a job, but a form of independence: "You're your own boss. You go when you know the fish are there." That freedom was spoken of with pride, even when the earnings were unreliable, and the future uncertain.

Still, the sea is changing. And so is the role of fishing. Fishers spoke of a generational shift: "Young people don't want to fish anymore. There are other jobs now. Tourism. Easier work." Another added, "If you see one person fishing on the shore now, it's something. Before, you would see five or six." Yet, as one fisher described, the visibility and pride of being a fisherman has always moved in cycles: "It comes and goes. It's in our tradition; it's in our blood. So, I don't think it will stop." What changes, they noted, is how hard it becomes to keep going when rules multiply and support disappears.

For some, fishing is now part-time, seasonal, or occasional: done out of passion rather than livelihood. As one fisherman

put it, "When you need a steady income, you cannot work as a fisherman here." Still, he fishes weekly: spearfishing, line fishing, going out when he can. "It fills the gaps," he said. It feeds his household, his neighbours, and sometimes strangers. In these quiet exchanges, fish traded, shared, or gifted, the sea remains a source of dignity.

3.1.2 Being Regulated Out of Existence

Yet that dignity is not always respected. Several fishers said that when new rules are proposed, "they don't ask us." One asked pointedly: "Fish that are banned for us are still served in restaurants. So, who are the rules for?" The disconnection between policy and practice is not just a procedural gap, but a political one. It speaks to what Olson (2011) calls the social consequences of privatization: not just who owns access, but whose lives are restructured or erased in the process. But regulation goes beyond zoning. The laws in Aruba also prohibit the catching of certain species like parrotfish, conch, or sea turtles, as well as the use of fishing methods like spearfishing, fish traps, and longlines in certain areas (AB 2006 no. 48; AB 2017 no. 48). These restrictions have real cultural weight. "Spearfishing is how we learned," one fisher explained. "That's how my father taught me." These lived experiences are mirrored in national data. As Boekhoudt (2014) notes in his fisheries review, overfishing and overcapacity have been documented in Aruba's small-scale sector, with fishing effort increasing while catch per unit effort (CPUE) has declined in all major fisheries (p. 83). More recently, Vermij et al. (2019) confirmed that Aruba's reef fish communities are heavily depleted, with large, reproductively important fish nearly absent across most sites and overall fish biomass critically low along the island's leeward coast. Despite these documented trends, no capacity reduction program has ever been implemented, and fishing continues under increasing strain. The effect is not just ecological stress but cultural erosion, as restrictions multiply without alternative livelihoods or meaningful support.

When laws limit not only where you can fish, but how and for what, they touch deeply on identity. They can feel not only like exclusions from space, but from a way of being. As Olson argues, privatization does not occur on its own, but it is shaped by who already holds power, and it often ends up reinforcing those inequalities. This is especially dangerous when cultural knowledge, passed on informally, and stored in daily practice, is systematically excluded from decision-making. What gets lost is not just economic viability, but the right to continue being who you are, on your own terms.
3.1.3 Resilience in Crisis, and the Question of Recognition
As some community members reflected, during COVID, people finally remembered the value of fishing: "The economy stopped. Tourism stopped. What you gonna do? Then you saw people going to the sea, trying to get something." In a crisis, the knowledge that had been undervalued became essential.

Fishing, then, is not in decline simply because of changing tastes or easier jobs. It is being made harder. Regulation and lack of consultation all compound to discourage younger generations from seeing fishing as viable. "It's not easy already," Fishermen said. "So don't make life more difficult for fishing." This plea shows what is at stake: not resistance to change, but a demand for recognition. A demand not to be forgotten in planning the ocean's future.

Cinner et al. (2012) write that in small-scale fisheries, ecological knowledge is embedded in social structure. Here, it is embedded in family, ritual, and place. What this section shows is not just the value of that knowledge, but the cost of ignoring it. Privatization may promise efficiency or ecological stability, but it comes with risks: the loss of memory, of community, of connection. The question is not only whether these measures work, but whether Aruba is willing to bear those risks and whether those most affected are even asked.

This section is not about loss in a nostalgic sense. It is about how identity and memory are formed through work,

through routine, and through connection to the sea. For fishers in Aruba, the sea is not just a means to survive, it is part of what makes them who they are. And when that relationship is interrupted by development, regulation, or shifting generational values, what is at risk is not only livelihood but a sense of belonging. What is clear from these conversations is that the sea holds more than fish. It teaches, it feeds, it remembers.

3.2 Privatizing the Ocean: Marine Governance in Practice

The previous section explored how fishers in Aruba experience the sea as livelihood, memory, and identity. This section shifts to the structures that increasingly constrain that relationship. It examines how marine governance—through zoning, conservation rules, and species bans—is made, enforced, and justified. Drawing on Olson (2011), Boekhoudt (2014), and interviews, it shows that governance is political: shaped by power, fragmented participation, and uneven access to decision-making.

3.2.1 From Participation to Fragmentation: The Problem of Process

Marine governance in Aruba is being reshaped through zoning plans, legal frameworks, and multi-use strategies aimed at managing the ocean more efficiently. Yet behind these technical structures lies a more intimate and unresolved question: who is the sea really for? Across interviews, participants described not just policy challenges, but a more fundamental disconnect: one of trust, access, and recognition. The sea is being regulated and zoned, but often without the people who have depended on it for generations.

One fisher captured this bluntly: "They never ask the fishermen... They just do it." Another, responding to the rollout of new marine protected areas (MPAs), asked: "So where are we supposed to go?" These are not rejections of conservation but refusals to be erased from decision-making. A third reflected, "They changed things, but we didn't know what was happening." Governance, here, is experienced not as inclusion but as something done to them.

From within the government, there is recognition of this gap. One official admitted, "Fishermen are the least I've seen in meetings." Another noted: "If I send an invitation today for a meeting next week, I can tell you, you won't see one fisherman there." Some see this as a failure of participation—but others pointed to deeper barriers. As one senior official explained, "I don't think the fishermen get a fair stakeholder input forum." He acknowledged how participation often appears more symbolic than real, "I can speak with three fishermen and say that's representative... but they forget to say: those are my friends." These informal dynamics, he noted, can create the illusion of inclusion while silencing the "hard questions" that real fishers would bring. In his view, the state lacks not intent, but infrastructure, and that absence creates mistrust. This dynamic reflects what Boekhoudt (2014) identifies as a top-down approach to fisheries management in Aruba, where decision-making remains largely "authoritarian" and "consultative," and where participation may occur through meetings or comment periods, but not through shared control or co-management (p. 84). Stakeholders are invited to react, but rarely to shape.

3.2.2 Rules Without Roots: Species, Methods, and Uneven Enforcement

This is where Olson's (2011) insights are crucial. She reminds us that privatization in fisheries is not always formal. It does not require ownership of quotas or the direct sale of access. Instead, it often works through exclusion, when access is restricted, participation is only symbolic, and legitimacy is consolidated in technical or bureaucratic institutions. This

subtler form of privatization is deeply felt, even if it remains invisible on paper.

In Aruba, this process unfolds not only through overlapping designations like MPAs, tourism zones, and spatial planning, but also through the regulation of specific species and methods. According to the Algemene Politieverordening (AB 2006 no. 48) and the Landsbesluit Bescherming Fauna en Flora (AB 2017 no. 48), several fishing practices are prohibited, including spearfishing with scuba gear, the use of certain nets, and the capture of protected species such as pink conch or sea turtles. These rules are not inherently unjust, but they are often perceived as poorly communicated or inconsistently enforced. A fisher asked: "Why are [they] banned for us but still served to tourists in some restaurants?" Gisbert Boekhoudt, head of Directie Natuur en Milieu (DNM) similarly acknowledged that while pink conch is a protected species under Aruban law, it continues to be imported from Belize and served in local restaurants and hotels. This is a contradiction that reveals the uneven enforcement and symbolic loopholes within current conservation frameworks. The concern is not the principle of protection but rather the sense that the rules are not applied transparently or equitably. As another government actor explained, "There's confusion everywhere. Not only the fishermen, we ourselves don't always know which law is enforced right now."

This legal and regulatory fragmentation makes marine governance feel inconsistent and reactive. Boekhoudt (2014) confirms this perception: enforcement budgets have declined over the past decade, while management costs have risen (p. 86). He notes that penalties are "scarcely applied" in small-scale fisheries, and that the "risk of detection is not high enough that participants try not to cheat" (p. 86). The system is thus under-resourced, and its legitimacy is weakened not only by poor communication, but by its inability to deliver consistent and fair enforcement. The result is a patchwork of enforcement, carried out sometimes by police, sometimes by NGOs, sometimes not at all. "They have meetings," another actor said, "but it's always the same people who speak. Some voices are missing." This fragmentation is not just logistical; it is emotional. It produces a governance system that feels imposed and detached from lived realities.

3.2.3 Beyond Access: Exclusion, Legitimacy, and the Politics of Sustainability

One fisher said, "They have meetings like that. They do what they didn't say at the meeting." Another added: "When they change the law, they lie to them." These are not critiques of regulation itself, but expressions of a broken relationship with policies experienced as distant, inconsistent, and exclusionary. A government actor described how this mistrust becomes self-reinforcing. Without clear and honest information, fishers begin to suspect that something is being hidden: "Once you lie to them, you lose it," he said. In a space already shaped by exclusion, even the perception of dishonesty can break an already fragile trust.

The slow erosion of legitimacy is central to how governance fails. As Jentoft, Chuenpagdee, and others (2007) argue, marine governance must be built not only on ecological or economic outcomes, but on the principles of participation, transparency, and justice. Without legitimacy, they note, even the most scientifically sound policy is likely to be resisted or ignored. In Aruba, many fishers are not against rules, but they are tired of being managed without a say. One put it simply: "If it's fair, no problem." What they object to is not order, but exclusion disguised as order.

Tourism, more than any other force, was seen as reshaping access to the ocean. Interviewees described the expansion of resorts, the docking of cruise ships in quiet bays, and jet skis skimming through coral zones. As Olson (2011) argues, privatization often privileges actors with capital and political alignment. In Aruba, this means tourism is

seen as legitimate and valuable, while traditional fishing is increasingly portrayed as outdated or even blamed. I have heard comments suggesting that fishers are the ones "overfishing," a claim that often goes unquestioned.

This governance regime is not declared as privatization, but it has the same effect. Access becomes narrowed. Space becomes claimed. And certain users, those with history but little formal power, become strangers in their own waters. Olson notes that this form of governance often hides behind the language of sustainability and order, but in practice, it redistributes visibility and voice. Fishers are excluded not just from meetings but from the narrative of what the sea is for. This exclusion is not incidental. It is structured. It reflects a larger political economy that ties marine planning to foreign investment, real estate value, and ecological branding. The sea becomes a "zone" rather than a relationship. As one organizational representative reflected, "It's always been fragmented." But fragmentation is not just a policy flaw but a lived disconnection. A breaking apart of relationships that once made the sea a shared space. And yet, as Section 3.1 shows, exclusion is never total. Fishers continue to resist erasure through everyday practice. What they demand is not exemption from governance, but a system they can trust. Some lifelong fishers spoke of how regulations had discouraged many over time: "We had problems going fishing in the park (MPAs). They were complaining about everything. So, a lot of people stopped." For others, fishing remains a lifeline not always as primary income, but as a practice of survival, connection, and fallback when other systems fail. "We have to keep our sea available always," one fisher said.

This is not just about livelihoods, but about rights, recognition, and responsibility. Fishers understand sustainability. Many spoke of releasing egg-bearing lobsters, respecting spawning seasons, and avoiding waste. What they ask is that their knowledge, their ethics, and their place be taken seriously, not filtered out through inaccessible processes or technical language. Jentoft et al. (2007) stress that co-management is only meaningful if it includes "procedural justice": a sense that decisions are made with people, not for them. In Aruba, that procedural justice remains elusive.

Ultimately, this section reflects a core tension: **Can a governance system be called inclusive if it does not fully engage those most affected by its outcomes?** Olson (2011) reminds us that privatization is not always intentional, but it can emerge through processes that gradually narrow access, limit participation, or prioritize certain visions of the ocean over others. In small island contexts like Aruba, where the sea carries both ecological and cultural weight, governance must remain sensitive to history, identity, and community ties.

Moving forward, the challenge is not simply to create more regulations or better enforcement, but to strengthen the relationships that governance depends on. That means improving communication, deepening trust, and creating space for meaningful participation: not just as stakeholders, but as partners in shaping the future of the sea. Marine governance, at its best, is not only about managing ecosystems. As a government official warned, "If you exclude the whole island from fishing, they will unite and then you have a problem." For him, governance is not about softening critique but preventing crisis by building respect. "You have to show them that not fishing in certain areas will improve catch nearby," he said. "That's what it takes."

3.3 Alternative Futures: Resistance, Adaptation, and Hope

While the previous section focused on how governance structures in Aruba often exclude those most affected, this section turns to the forms of agency that endure despite those exclusions. Resistance here is not loud or confrontational but quiet, persistent, and rooted in care. It

is the act of continuing to fish, to teach, to speak, even when space to do so is shrinking.

What follows is not a critique of governance, but a recognition of the everyday strategies through which fishers show presence and possibility. This section shifts from exclusion to imagination, showing that most fishers are not rejecting rules outright but they are asking to help shape them. Their demand is not for exemption, but for recognition as rightful stewards of the sea.

3.3.1 Informal Resistance and Local Conservation Practices

For many fishers in Aruba, resistance does not look like protest. It is quieter than that, such as showing up in the decision to keep fishing, to pass on knowledge, and to keep speaking, even when it feels like no one is listening. These acts are not about rejecting rules, but they are about protecting relationships: with the sea, with each other, and with the knowledge passed down through generations.

What came through in many interviews is that fishers already practice forms of conservation. One person explained: "If the lobster has eggs, we don't harvest it. We let it breed. If it's a fish that's a small size, we let it grow, let it reproduce. That way you can still contribute to the growth and harvest the fish." Others shared how some official rules don't match the reality of life at sea. "You cannot put a catch limit," one fisher said, "because some days… if the catch limit is two and I catch two today and tomorrow I catch nothing, who's going to compensate?"

The issue is not with sustainability itself, but with how it is decided: often without consultation or explanation. Several participants described how new rules or projects were introduced without warning. One recalled hearing about a proposed fish farm only after they believed the contract had already been signed: "They signed it already, it's going to come there. Just heard that, and everybody opposed it." This likely referred to the case of Petros Aquafarming, which was mentioned in local newspapers as if it had been approved even though formal decisions had not yet been made. But because no one from the community had been properly informed, many believed it was already happening. Another described the broader feeling, in Spanish: "They came with the law and passed it for hunger."

These experiences show a deeper pattern: decisions made from the top down, with little room for dialogue. As one fisher said, "Get their concerns, see what they're worried about, and try to work with them. It can't be done [without that]." This is not a call to reject governance, but a call to do it differently—through listening, trust, and mutual respect.

3.3.2 Barriers to Representation and Collective Platforms

One government actor reflected on this clearly: "It would be very helpful if the fishermen had a united voice; no strong fishing platform, like a syndicate", he said. He noted how fishers' independence, something often seen as admirable, can also complicate formal participation. But this also means there is no central mechanism through which to collectively respond to proposals or voice concerns. Without organized representation, even the most well-meaning participatory processes may fail to reach those most affected. This absence is echoed in Boekhoudt's (2014) review, which notes that fishers are not formally organized into stakeholder groups, and that participation is not embedded as a required part of management (p. 84). As a result, platforms for collective voice remain limited and informal.

In nearby Bonaire, similar issues of fragmentation were addressed through the formation of a fishers' association supported by community advocates and researchers, including Stacey MacDonald. Her work with small-scale fishers helped establish clearer lines of communication

between community members and policymakers and laid the groundwork for more effective, bottom-up governance models (MacDonald, 2021). Aruba could benefit from similar efforts: not by imposing structure, but by supporting community-led platforms for collective voice and recognition.

One governmental actor also insisted that the state must do its part: "Don't pretend it's good when it's not. If it's bad, say it's bad. But don't lie—once you lie to them, you lose it." His call was not for perfection but for honesty and mutual responsibility. This echoes Olson's (2011) argument that governance is not only about maps and mandates but about whose knowledge is recognized and whose is dismissed.

3.3.3 Bridging Knowledge Systems for Inclusive Governance

In Aruba, this disconnect is not only about language, but government actors also often speak in technical terms: policy targets, spatial zones, and sustainability frameworks. Fishers speak in currents, seasons, and instinct. "Sometimes the sea condition is good. But you won't... the ocean current isn't coming for the fish. There's no bait, there's no fish," one person explained. This kind of embodied ecological knowledge rarely appears in formal documents, yet it is critical to the success of any marine strategy. As Olson (2011) notes, power in ocean governance lies not only in who gets to speak but in what kinds of knowledge are made legible.

Bridging this gap requires sustained interpretation, long-term dialogue, and institutional humility. "It has to be like a full-on education first," one fisher recommended. "Inform the fishermen. Get their concerns... It can be done." Others echoed this, calling for youth programs, skill-building, and platforms that support traditional knowledge transfer. "If there were investment in that, you'd have more fishers," one interviewee said, "and more stability, too." Education, here, is not only technical. It is social and symbolic. As one actor noted, "Very few young people take it up early. They don't like getting seasick." In a context where tourism is seen as more profitable and less physically demanding, fishing must be made viable: not just economically, but with dignity. That means celebrating it as a profession, supporting intergenerational transmission, and ensuring that regulation does not inadvertently criminalize longstanding practices.

Importantly, resistance in Aruba was not simply defensive. It also contained vision. Fishers spoke of balance, co-existence, and proposals for improvement, such as placing aquaculture sites in non-fishing areas or developing systems that allow both tourism and traditional use to thrive. One interviewee emphasized: "Hear the concerns and then balance it out." Hope, then, lies not in perfect prints, but in the willingness to co-create. As Olson (2011) reminds us, governance is not a fixed destination but a process, one that depends on mutual recognition and evolving relationships. This aligns with broader research on small-scale fisheries, where community-based management has been widely explored as a just and effective approach (Jentoft et al., 2007; Cinner et al., 2012). But for such models to succeed, they require time, trust, and the recognition that different actors bring different, but equally valid, knowledge systems. They also require sensitivity to power and an understanding that participation is not only about being invited, but about being heard, respected, and able to shape outcomes.

For this to happen in Aruba, new kinds of spaces are needed; not just workshops held after decisions are made, but collaborative processes from the outset. Not just translations of policy into local languages, but mechanisms that allow different ways of speaking, knowing, and feeling to shape policy itself. Respect cannot be a formality but a must to be practiced in every part of the governance process. Ultimately, what is at stake is more than fish stocks or marine zones: it is the future of a marginalized community that has

always lived with the sea and now must find a way to live with change. What the interviews in Aruba reveal is not a community resisting governance, but a community asking to be part of it. The knowledge is there. The care is there. The willingness is there. What remains is the challenge of building a governance system that listens with the same patience the fishers have long shown the sea.

4. Discussion

This research began with a simple question: how fishers in Aruba experience and navigate marine governance. But what it uncovered was a more complex story that was not just about rules or policies, but about displacement, memory, and power. Beneath the surface of conservation zones and method bans lies a deeper process of soft privatization, where marine space is increasingly structured by logics that exclude those who have lived with the sea the longest.

As Olson (2011) reminds us, privatization is not always declared. It can operate quietly, through zoning, bureaucratic complexity, or participation that arrives too late. In Aruba, this process appears in the layering of MPAs, tourism expansion, species restrictions, and fragmented enforcement. Fishers are not resisting rules but the feeling of being managed out and erased from decisions, from language, from the future. One called it directly: "They never ask us. They just do it."

This is not just about ecological governance but about political economy. As Leotaud (2023) writes of the wider Caribbean, the push for "blue growth" has often meant the rebranding of enclosure: cruise terminals, tourism zones, and conservation efforts that displace small-scale fishers while appealing to international standards of sustainability. Aruba is not exempt from this. In fact, its small size and dependence on tourism make the process sharper. Privatization here happens not just in property titles, but in the stories that get told about who the ocean is for and whose presence is inconvenient.

This paper does not argue that all regulations are harmful. Most fishers interviewed understand limits. The problem is not conservation itself, but the way governance unfolds: disconnected, symbolic, or rushed. Even within the government, there is recognition of this. This is not just a policy issue but a crisis of relational infrastructure: the time, trust, and coordination needed to build decisions together. So how might Aruba begin to shift course not just toward better management, but toward justice?

First, Aruba could launch a community-led co-management group in one or two nearshore areas. This would not be a consultation group, but a site of real shared authority. Fishers, NGOs, and government actors would co-develop management strategies for species, zones, and enforcement, based on lived knowledge, not just technical plans. This space would not require massive funding. It would require continuity, transparency, and recognition of informal expertise. It would also directly challenge the pattern Olson warns us about: the kind of privatization that hides behind good intentions.

Second, Aruba should invest in community-led intergenerational storytelling and mentorship not as a heritage project, but as a living governance tool. Elders who carry sea knowledge, currents, seasons, ethics, could mentor interested youth, while also shaping public narratives about who the fishers are and why they matter. This builds visibility, not as branding, but as power. As Guy Standing argues in The Blue Commons (2022), reclaiming the blue commons means resisting the cultural erasure that often precedes enclosure. In Aruba, that starts by giving value to the people who have always been there: before the laws, before the resorts.

These are not solutions, but they are shifts toward governance that listens early, speaks honestly, and stays close to the communities it affects. What this research shows is that fishers in Aruba are not against change. But

they are tired of being asked to adapt to systems that do not adapt to them.

This research, of course, has limits. It captures a small number of voices during a short window of time. It cannot represent every perspective, nor claim to have mapped the entire complexity of marine governance on the island. What it can offer is a snapshot: a glimpse into how policies feel, and into the kinds of everyday wisdom that often go unheard. The sea, in this context, is more than a resource: it is history, memory, livelihood, and identity. The answers may not be simple. But they are already here, waiting, just like the fishers themselves, for someone to ask.

5. Conclusion

For me, this research has also been personal. I came to Aruba to learn, and what I found was a community that welcomed me, challenged me, and trusted me with their stories. I felt genuinely that I owed something back. I came to listen, and in listening I came to feel a kind of responsibility: not to speak for anyone, but to make sure that what was shared was not lost in silence. These stories stayed with me long after the interviews ended. They shaped not just this research, but the way I now think about sustainability, governance, and justice.

This paper is not a solution, but it is a beginning. A way to hold open space for a conversation that must continue not because it is easy, but because it matters. I am grateful to everyone who welcomed me into that conversation. This is, in some small way, my way of saying thank you.

Sustainability, in the end, cannot be built only on data, zoning maps, or enforcement plans. It must also rest on relationships—between people and place, between institutions and communities, and between different ways of knowing. If marine governance is to succeed in Aruba, it will need to grow not just in complexity, but in compassion. That work has already begun. The challenge now is to keep listening.

In a time when oceans are carved into zones and claims, this research is a reminder: the sea is not just space, it is relationship. And governance, to be just, must begin there.

Figure 1. Fishing Boats near the Shoreline, Aruba
Photograph provided by Byron Boekhoudt, April 3, 2025. The image shows small artisanal fishing boats anchored close to the beach, with palm trees and coastal development visible in the background, illustrating the intersection of local livelihood and tourism infrastructure.

References

- Boekhoudt, B. G. (2014). Country review: Aruba. In FAO (Ed.), Review of current fisheries management performance and conservation measures in the WECAFC area (FAO Fisheries and Aquaculture Technical Paper No. 587, pp. 79–88). Food and Agriculture Organization of the United Nations.
- Cinner, J. E., McClanahan, T. R., MacNeil, M. A., Graham, N. A. J., Daw, T. M., Mukminin, A., Feary, D. A., Rabearisoa, A. L., Wamukota, A., Jiddawi, N., & Campbell, S. J. (2012). Comanagement of coral reef social-ecological systems. Proceedings of the National Academy of Sciences, 109(14), 5219–5222. https://doi.org/10.1073/pnas.1121215109
- Hardin, G. (1968). The tragedy of the commons. Science, 162(3859), 1243–1248. https://doi.org/10.1126/science.162.3859.1243
- Jentoft, S., Chuenpagdee, R., Bundy, A., & Mahon, R. (2007). Challenges in the implementation of the ecosystem approach to fisheries management. Marine Ecology Progress Series, 300, 275–279. https://doi.org/10.3354/meps300275
- Leotaud, N., Girvan, A., & Jattansingh, S. (2020). The Blue Economy winners and losers in the Wider Caribbean. In Routledge eBooks (pp. 21–34). https://doi.org/10.4324/9780429342233-3
- Mac Donald, S. (2021). Life in "paradise"; A social psychological and anthropological study of nature conservation in the Caribbean Netherlands. Universiteit Leiden. https://scholarlypublications.universiteitleiden.nl/handle/1887/3304059
- Olson, J. (2011). Understanding and contextualizing social impacts from the privatization of fisheries: An overview. Ocean & Coastal Management, 54(5), 353-363. https://doi.org/10.1016/j.ocecoaman.2011.02.002
- Partelow, S., Abson, D. J., Schlüter, A., Fernández-Giménez, M., Von Wehrden, H., & Collier, N. (2019). Privatizing the commons: New approaches need broader evaluative criteria for sustainability. International Journal Of The Commons, 13(1), 747. https://doi.org/10.18352/ijc.938
- Schlüter, A., Bavinck, M., Hadjimichael, M., Partelow, S., Said, A., & Ertör, I. (2020). Broadening the perspective on ocean privatizations: an interdisciplinary social science enquiry. Ecology And Society, 25(3). https://doi.org/10.5751/es-11772-250320
- Standing, G. (2022). The blue commons: Rescuing the economy of the sea. Pelican Books.
- Vermij, M., Marhaver, K., Estep, A., & Sandin, S. (2019). Coral reefs baseline study for Aruba. CARMABI Foundation & Scripps Institution of Oceanography. https://publico.aw/assets/data/reports/20221213A/carmabi_aruba_report_final.pdf

Legal documents:

- AB 2006 no. 48. Algemene Politieverordening van Aruba [General Police Ordinance of Aruba].
- AB 2017 no. 48. Landsbesluit Bescherming Fauna en Flora [National Decree on the Protection of Fauna and Flora].

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A rollercoaster without a speed limit.

You can say a lot about this experience on Aruba, but it was not boring. When calling with a friend, he mentioned; 'well for sure you are living.' Because it was like life with its ups and downs, but than, as a rollercoaster, not respecting its speed limit. The first three weeks felt like life on paradise, the perfect balance between work-and-life, but than on a tropical island. In the beginning after the hours of meeting in the reception on Aruba Blue Village on the development of our project, swimming clothes were put on, and we jumped in the car to chase the sunsets of Aruba.

The project by itself was very challenging, how do you start with improving food security on an island? There is so much stuff to consider, and trying to integrate the distinct interests of the stakeholders into a common project that would work best for all, is a difficult objective to achieve. Our group was highly motivated, and we pushed and supported each other to make it happen. Aquaculture, as a novice food production system which still needs a lot discovering, was a supercool subject to dive in, especially how it could be integrated into the fragile marine ecosystem of Aruba. Besides aquafarming, learning about the Aruban fishing culture and their struggles provided a unique hand-on experience on how communities are needed to be considered in policy making. Lastly the weekly reflections and classes made me aware of how sustainability challenges become more evident on SIS such as Aruba.

As someone passionate about nature, obtaining my diving license was for sure a highlight, as I was able to witness the marine ecosystems and its beauty it has to offer. At the same time, it was a depressing sight to see the number of skeletons of dead corals, that were once thriving at the beaches of Aruba but have been degraded by the commercialization of the island. The work that was put in for active restoration and being able to see the artificial reefs, was very inspiring.

Next to the cool project, the diving experience and the chasing of sunsets, you could kite and perhaps go to Costa Rica? There was so much to offer, that as someone who always wants to do everything, it could be overwhelming. Ultimately, I realized it is not necessary be everywhere.

Living with the same group of twelve people intensively for three months was an interesting experience. I became very good friends with people in a short period of time, listened to their life stories and created new ones: sharing dinners every night, going out in the weekends, having hard study sessions, swimming drunk in the ocean underneath the stars, I will keep these memories for a life-time. At the same time tensions build up which ultimately can explode into unnecessary confrontations. As an open book myself, I really got to learn that people can be different than you and how they resolve things. But for sure I was reminded that the best way to resolve 'little tensions' is by talking about them in 1 on 1 conversations, instead of talking behind your back or in group occasions. Luckily, in these open conversations you get to understand each other and get even closer.

In the end, I am proud of the project we delivered, but mostly grateful for the experience I got to have and the people I have met which I can now call my good friends. I want to thank the Aruban students and Eric that welcomed and helped us managing life on the island, the stakeholders we got to learn from for our project and the 11 people that made this experience thoroughly memorable. I will miss you Aruba.

A Critical Assessment of the Feasibility of Sustainable Aquafarming on Aruba: a Deep Dive into the Carbon Footprint and Eutrophication Potential

Plym Hesseling

1. Introduction

Aquaculture has been the fastest developing food sector in the past 30 years, currently providing half of the fish supply in the world and projected to keep increasing in the coming decades (Troell et al., 2014). Proponents for upscaling aquaculture emphasize its opportunity for addressing nutritional deficiencies (Garlock et al, 2022) and its lower environmental impact compared to alternative animal sourced foods (Gephart et al., 2020). Aquaculture is even mentioned as a necessary alternative for global wild-fishing, as the latter is mentioned to go far beyond its sustainable limits (Costello et al., 2020). Aquaculture, on the other hand, is said to still be far below its ecological limits, with space for growth to meet the increasing global demand for fish (Costello et al., 2020).

Approximately 40% of the terrestrial land globally is used for cultivation and grazing, and land clearing for this has contributed to rapid loss of species diversity (Herrero et al., 2015). Next to that, the cultivation of feedstock has unsustainable freshwater use (Mekonnen & Hoekstra, 2012). Aquaculture has the advantage of requiring limited sea space per kg of food output (Froehlich et al., 2018) due to the use of space in m3 instead of m2 in which aquaculture can grow. Additionally, it requires little freshwater consumption (Troell et al., 2014).

For Aruba, as an island with limited land and little freshwater availability (Mijts et al., 2023), the marine areas surrounding the island offer great potential for food production. Since the Aruban economy is 88% dependent on tourism for its GDP (Boyer et al., 2024), it can be a mechanism to reduce dependence on food imports and increase economic diversification.

Furthermore, fish is a highly consumed product on the island: average seafood consumption in Aruba per capita was 53 kg per year (in 2015–2017). In the same period, the global average seafood consumption per capita was 20 kg (De Vlieghere et al., 2023). The local fish production cannot keep up with the demand ensuring that approximately 82% of the seafood consumed in Aruba is imported (De Vlieghere et al., 2023). Therefore, aquafarming companies like Petros seek to utilize the marine areas for red snapper cultivation (Innovasea, 2024).

However, there are also ecological risks related to aquaculture on Aruba. The marine ecosystems in Aruba are already in a poor state (NGO, personal communication). Natural coral cover has decreased from 34.8% in 1970 to 16.3% in 2011, due to pollution, overfishing, coastal development, coral bleaching, diseases and invasive species (Jackson et al., 2014). Therefore, local environmental NGOs are generally opposed to aquaculture on Aruba (NGO, personal communication), because of its potential to create additional, cumulative environmental impacts, which could be detrimental for the already degraded system (NGO, personal communication).

One possible way to mitigate these risks is **Integrated Multi-Trophic Aquaculture (IMTA)**, which incorporates filter-feeders like mollusks and seaweed alongside fish farming. These species naturally absorb excess nutrients, reducing eutrophication (Petersen et al., 2018; Jiang et al., 2019). IMTA could be particularly relevant for Aruba, where marine ecosystems are already in decline and further environmental stressors could be detrimental.

This study aims to provide an overview of the environmental challenges related to aquafarming, with a specific focus on the impacts of nutrient pollution and CO_2 emissions on the marine ecosystem of Aruba. It will also assess the potential of an IMTA system to mitigate nutrient pollution compared to conventional fish farming. The actual eutrophication reduction potential of IMTA will be evaluated, and the carbon footprint of fish from an IMTA system will be compared to imported fish. By doing so, this study hopes to determine whether local fish production with limited nutrient pollution in Aruba could reduce CO_2 emissions and, consequently, mitigate global warming and ocean acidification impacts on marine ecosystems.

2. Literature Review

Aquaculture has three environmental challenges which hinder it from being a sustainable food source. There are two ways that could possibly mitigate the environmental impact: adequate location planning and adopting new methods such as IMTA.

2.1. Nutrient pollution from aquafarming

In Aruba, there are already issues with excessive nitrogen and phosphorus release originating from three sewage plants along the Leeward shore and four unofficial sewage dumps in Aruba (Vermeij et al., 2019). The resulting eutrophication is seen as a main driver of the increased stresses on the marine ecosystem (Vermeij et al., 2019). It can lead to algae blooms on the water surface, as these extra nutrients allow for rapid growth far beyond the carrying capacity of the water. This increases turbidity of the water and blocks the sunlight that the microalgae on corals situated deeper in the water (zooxanthellae) require for photosynthesis. For corals that thrive in oligotrophic conditions of the Caribbean (nutrient-poor waters), as they gain 60-85% of their nutrients via photosynthesis (Fuijse et al., 2014), eutrophication would cause severe stress.

In extreme situations, eutrophication can lead to severe oxygen depletion or 'hypoxia'. This is caused by organisms which decompose the organic waste, which require oxygen for this process and grow exponentially with accumulated nutrients. Hypoxia makes corals more vulnerable to bleaching events. Areas with hypoxia showed 76% bleached corals compared to 2% in normal conditions (Altieri et al., 2017). In Curaçao, these hypoxia events have created dead zones (Vermeij et al., 2019). Especially bottom or benthic communities directly underneath the nutrient waste are vulnerable; in Aruba excessive nutrient waste has resulted in anoxia at the sea-bottom, a situation where oxygen gets fully depleted (Halewijn et al., 1992. Cyanobacteria and algae now dominate the sea bottom (Vermeij et al., 2019).

Aquaculture causes an additional risk of eutrophication, due to nutrient pollution from fish culture (Wu, 1996). Since only 13 to 43% of N and 18 to 36% of P of feed inputs are retained by species in conventional fish farming, the rest gets released in the water (Nerderlof et al., 2021). This mostly affects the marine environment directly underneath a fish farm. Nitrogen mineralization mainly occurs in oxygen-rich environments. The sediment underneath the fish farms is normally anaerobic and without any bioturbation, ensuring that little to no nitrogen is being demineralized (Wu, 1996), creating a net accumulation of a great stock of Nitrogen. This typically leads to a dead zone in the benthic communities underneath and in the vicinity of fish farms. These can extend up to a 1 km radius around

the fish farm (Wu et al., 1994). In Aruba, due to the already existing pressures on the ecosystem, it is essential to look for aquaculture options with minimal nutrient runoff.

Figure 1: image coral bleached and overgrown by bacteria in an hypoxia event (Altieri et al., 2017)

2.2. Invasive species

The Caribbean Ocean is the most isolated tropical ocean on the planet, many species have little evolutionary experience in dealing with exotic species before the advent of people (Jackson et al., 2014). Therefore the introduction of non-native species (NNS) via escaped farmed fish is a major concern which needs to be avoided. In other regions of the world, escaped farmed fish such as cobia in Ecuador, have quickly established populations in non-native waters, outcompeting local species and disrupting ecosystems (Castellanos-Galindo et al., 2018). Similarly, algae farming, if not carefully regulated, can lead to invasive species that damage coral reefs, as seen with Kappaphycus alvarezii in Hawaii and the Gulf of Mannar (Salimi et al., 2021).

2.3. The effect of CO2 emissions on marine ecosystems

Lastly, the CO2 emissions originating from aquaculture also indirectly damage the marine ecosystems in Aruba. First of all, it causes the seawater temperatures to rise, which can lead to coral bleaching events (Brown et al., 2019). However, more importantly, the oceans absorb a large share of the anthropogenic CO2-emissions, leading to ocean acidification (Doney et al., 2009). If CO2-emissions would rise according to the business-as-usual scenario from the IPCC (IPCC, 2021), pH could decrease by 0.4 by the end of the 21st century. Meaning that H+ concentration would approximately increase by 150% and carbonate ion concentration would decrease (CO_3^{2-}) by 50% (Orr et al., 2005).CO2 namely reacts with H2O to form bicarbonate (HCO_3^-) and H+. This consequently reduces the carbonate ion (CO_3^{2-}) concentration low due to changes in the pH of the ocean. Carbonate ion is necessary for calcium carbonate ($CaCO_3$) formation (Doney et al., 2009). Calcium carbonate is essential for the reef-building of corals and shell formation of many other marine organisms, a decrease in its concentration would be disastrous for the coral reefs.

2.4. Location

One of the most key decisions in mitigating both environmental and social risks lie in the spatial planning of aquaculture sites. According to recent modeling, strategic placement alone can reduce cumulative environmental impacts by up to 34.7%, even under scenarios of increased global seafood demand (Ma et al., 2025). In contrast, poor site selection can result in an increase in cumulative impacts. For Aruba adequate placement means avoiding marine protected areas (MPAs) and reef systems. Placement in areas with strong offshore currents ensures that nutrients will be dispersed (Buck et al., 2018), which could lower nutrient concentrations and mitigate environmental impacts. Based on research by Welch et al. (2019), who conducted a study on the difference between nutrient concentrations in proximity of the fish farm and control sites on a proper distance in the Caribbean, nutrient concentrations get significantly diluted, as the research showed no significant differences in nutrient concentrations. Lastly, the far off-shore placement was favored by many stakeholders on the island (Local fisherman, NGOs, personal communication).

2.5. IMTA

However, nutrient dispersion is not the solution to pollution (NGO, personal communication). Additional methods must be considered to minimize cumulative eutrophication. In contrast to fish farming, seaweed and mollusk farming present promising environmental benefits. Instead of creating additional nutrient waste, these species feed themselves by filtering out nutrients from the water (Petersen et al., 2018; Jiang et al., 2019) and can be utilized as active mitigation tools to clean eutrophic waters (Jiang et al., 2019). Seaweed actively takes up nitrogen and phosphorus from the water. A 68000 ton kelp farm (wet weight), was estimated to remove 297 tons of nitrogen and 42 tons of phosphorus from the bay annually (Jiang et al., 2019). Mollusks actively take up phytoplankton and the particulate organic nutrients and store them in their tissue (Petersen et al., 2018). The first studied area for mussel cultivation for the purpose of nutrient removal besides harvesting, showcased 16 t of nitrogen and 0.7 t of phosphorus removal per 1100 tons of mussels (Petersen et al., 2014).

These mitigating properties could also be used to reduce nutrient pollution caused by fish farming. **Integrated Multi-Trophic Aquaculture (IMTA)** systems (figure 2) has been presented as a possibility to integrate conventional fish farming with seaweed and mollusks. Waste from fish, such as uneaten food and excretions, is taken up by these filter feeders, imitating natural ecosystems (Chopin et al., 2001). Studies indicated that IMTA systems achieve lower life-cycle eutrophication and acidification impacts compared to typical monocultures (Hala et al., 2024). Besides mitigating eutrophication, the active nutrient uptake could consequently also boost the growth of filter feeders in nutrient-poor waters like those around Aruba (Nederlof et al., 2021; Filgueira et al., 2017), as fish waste may provide up to 90% of their diet (Salud Deudero et al., 2011).

Furthermore, these species can be used as a potential mechanism to mitigate global warming via the sequestration of carbon (Feng et al., 2022; Lian et al., 2023). Mollusks take up dissolved organic carbon and store it in calcium carbonate which constitute their shells (Turolla et al., 2020) and seaweed captures it via photosynthesis.

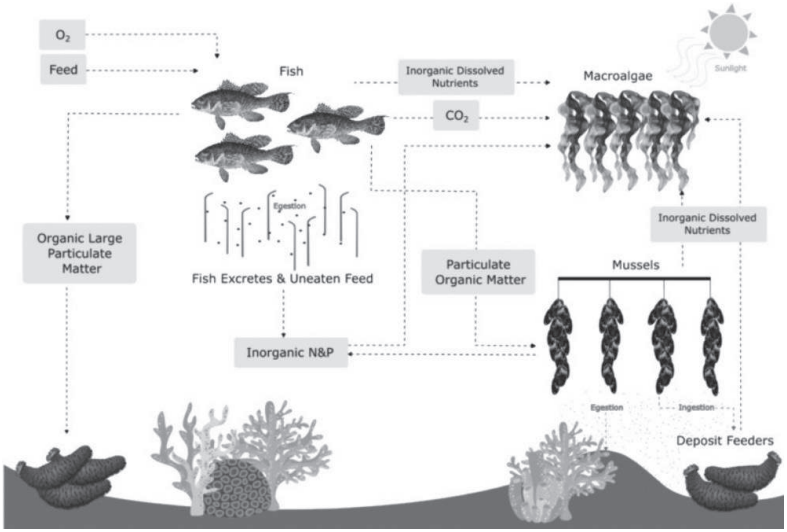

Figure 2: A diagram of an IMTA system (Hala et al., 2024)

3. Methodology

To assess the carbon footprint of an IMTA system and its mitigation potential, a literature review on Life Cycle Assessments (LCAs) was conducted. A LCA is a standardized framework designed to estimate potential impacts associated with producing a product by quantifying and estimating resources consumed and compounds emitted into the environment during all stages of its life cycle, from raw material extraction up to the end-of-life (Guinee, 2002). Therefore, it is a powerful tool to showcase the carbon footprint of produced fish via aquaculture. This research takes a cradle-to-factory gate approach, which means that carbon emissions after production, originating from distribution after production of the end-product from the factory gate, consumption and end-of-life treatment are not accounted for. The functional unit within this research is the kgCO2e/kg of fish.

Unfortunately, globally there are a limited number of current far-offshore open water applications of IMTA (Buck et al., 2018). Current IMTA applications do exist in tropics, but are mostly located on land (Troell, 2013). Therefore, the carbon emissions were calculated using LCA studies of different locations all over the world of the species across the different trophic levels that exist within an IMTA system. Studies were chosen based on whether the case study considered an offshore aquaculture practice, whether it clearly mentioned the direct energy requirements per unit of output, included eutrophication numbers and preferably if it also showcased the distance of the farm to the coast. Three LCA-studies for fish farming were included (Garcia et al., 2019; Bujas et al., 2022; Ayer & Tyermers, 2008), three for seaweed farming (Nilsson et al., 2022; Li et al., 2024; Thomas et al., 2020) and four for mollusk culture (Turolla et al., 2020; Liourgiou et al., 2017; Summa et al., 2023; Aubin et al., 2018).

The carbon footprint per study was assessed according to the steps below. After this assessment, an average footprint was calculated of fish, seaweed and mollusks. The carbon footprint across the different cultivation systems will be discussed and that of three cultivation systems will be combined into the carbon footprint of an IMTA. Different IMTA scenarios with different ratios of species are developed and further explained in the results section.

3.1. Eutrophication

Eutrophication potentials of gPO4eq/kg of output were retrieved from the studies. For the fish farms these numbers were directly copied. The eutrophication values for mollusk farms did not always include the potential of nutrient uptake within their LCA-values, as these LCA-values only considered the eutrophication caused by production, while mentioning the numbers on nutrient uptake separately (Turolla et al., 2020; Liourgiou et al., 2017)). In those cases the N fixation and P fixation were converted to PO4eq and subtracted from the eutrophication potential. Only one LCA study on seaweed considered nutrient uptake within their study (Thomas et al., 2020), this number (-2.88 gPO4eq/kg) was assumed to be the same for the other studies and was subtracted from the eutrophication potential mentioned in the studies.

3.2. Carbon footprint of fuel

Fuel costs were altered according to the distance described in the LCA studies and a hypothetical 8 km distance offshore placement of an aquafarm in Aruba. This far offshore distance was chosen as this was preferred by most interviewed stakeholders. Distances of the LCA studies were either retrieved from the study, or assessed using QGIS. The assumption was made that the fuel costs do not increase linearly with distance, since the specific fuel oil consumption (SFOC) increases significantly with lower engine loads by 1.25 times (Åsøy, et al. 2024). In other words, the fuel to power ratio is lower when the boat is not giving its maximum power. Which occurs mostly during

harboring occasions, when the boat has to break and turn, or during leaving when the boat needs to accelerate. With longer distances the boat will run more on higher engine loads, reducing the amount of fuel wasted. Therefore, a formula was assembled which accounts for this lower SFOC and the reduction in relative time spent harboring with increasing distance. So to assess the fuel costs per kg of output from aquaculture on Aruba, the following formula was created:

$$Fadj=(Fbase\times(8/X)\times S_{SFOC})$$

Where Fadj= the adjusted fuel requirement for Aruba (MJ), Fbase the fuel costs from the studies (MJ), X (km) is the distance retrieved from the studies and S_{SFOC} is a factor made to address the 25% lower efficiency on lower engine loads:

$$S_{SFOC}=1-0.25\times(1-8/X)$$

After the energy requirement for fuel was assessed, the carbon footprint was calculated. Diesel was assumed to be the sole fuel source, which has a carbon footprint of 74 $kgCO_2e$/MJ (from table 2.3. from Blok & Nieuwlaar, 2021).

3.3. The carbon footprint of electricity

The assumption was that the electricity requirement does not differ between the researched studies and the situation in Aruba, so these were directly copied from the studies. All electricity was assumed to originate from the power produced by WEB (WEB, 2023). The electricity requirements per step were mentioned in detail in some studies, these values were summed up to provide the total electricity requirement. For both the mollusks and the seaweed, not all studies included the further electricity requirement for cleaning and processing. These missing values were leveled out by including numbers from other studies.

The carbon footprint of a kWh of electricity from the grid was assessed according to the energy mix from Aruba, which currently originates for 83% from Heavy Fuel Oil, and for 17% from renewable energy (WEB, 2023). A fuel to power efficiency of 46% was assumed (U.S. Environmental Protection Agency, 2015). The Energy requirement for Energy (ERE) was included, which assesses the energy required per MJ required for the extraction, transportation, storage and refining. It was assumed that this was 1.12 MJ/MJ for heavy fuel oil using percentage ranges table 8.1. from Blok & Nieuwlaar (2021), for wind energy this was assumed to be 1.055 MJ/MJ based on EROI values from Hall et al. (2013). All energy requirements for energy were assumed to be provided via oil. Eventually, this showcased that 2.03 MJ of oil was required per MJ of electricity output. The carbon footprint was calculated using table 2.3 from Blok & Nieuwlaar (2021), which led to an estimation of 0.534 $kgCO_2e$/kWh of power.

3.4. The carbon footprint of indirect inputs

The carbon footprint of constant indirect inputs include the fish feed and the fresh water requirement. The carbon footprint of fish feed was based on Cargill (2022) and BioMar (2023), which are fish feed producers which use 46.2% and 64% of plant material and only consists of 9.6 to 23% of marine feed. In the past, fishes were given 2-5 times as much fish protein as the fish protein supplied by the product (Naylor et al., 2000). These are also the companies where Petros retrieves its fish feed from (Petros, personal communication). By utilizing Feed Conversion Ratios (FCR) of 1.5 and including the edible percentage of fish (Petros, personal communication), the carbon footprint of fish feed per kg of edible fish could be calculated. Compared to other studies the used FCR is conservative (Garcia et al., 2019; Abdou et al., 2017).

The carbon footprint for freshwater usage for both seaweed and mollusks was included. No clear numbers on kWh

required per m^3 of water were given by WEB, excluding the possibility to do carbon footprint calculations. Therefore, a carbon footprint of 2.96 kgCO2e/m^3 of fresh water was retrieved from the website of WEB (2023).

3.5. Carbon footprint of material production

The carbon footprint of material production was assessed by retrieving the global warming potentials and the relative share of material production of this potential from the LCA studies.

3.6. Carbon sequestration

Carbon sequestration via seaweed occurs via carbon conversion into biomass (C_{PROD}), particulate organic carbon which is buried in the sediments in the long-term (C_{SED}), and the fraction of dissolved organic carbon which resists degradation (C_{RDOC}) Pessarrodona et al., (2024), only considers C_{SED} and C_{RDOC} as actual sequestration, since most of seaweed is used for short-lived products that do not store carbon long-term. On the other hand Thomas et al., (2020) considers all carbon uptake as carbon sequestration. This different allocation creates a substantial difference in actual carbon storage, including C_{PROD} results in 0.169kgCO_2e/kg (Lian et al., 2023, own calculations) fresh weight seaweed. Only including long-term sequestration would make the carbon uptake negligible to 0.009 kgCO_2e/kg of seaweed (Lian et al., 2023, own calculations).

In this study, the progressive assumption that the carbon sequestration also considers the carbon uptake within the end-product will be made. Carbon uptake would be estimated at the average between Thomas et al. (2020) and Lian et al., (2023), equal to -0.157 kgCO_2e/kg seaweed.

Two (Turolla et al., 2020; Aubin et al., 2018) of the four mollusk studies considered carbon sequestration within their study, the average between this was taken, which was equal to -0.361 kgCO_2e/kg, which is on the conservative end compared to global assessments of carbon sequestration potential for mollusks (Feng et al., 2022).

3.7. Carbon footprint of imported fish

The carbon footprint of 1 kg of imported fish will be retrieved from De Vlieghere et al. (2023), who conducted a LCA on 1 kg of canned tuna. Most of the imported seafood arrives frozen or in cans. Within all canned seafood products, people spent most (69%) of their budget on canned tuna (Vlieghere et al., 2023; Central Bureau of Statistics Aruba, 2019). Due to its high consumption on the island this product is chosen to be suitable for a comparison between locally produced and imported fish.

3.8. Carbon footprint of an IMTA system

To calculate the carbon footprint of 1 kg of fish originating from an IMTA system 8km off the coast from Aurba, the carbon footprints of electricity, material and indirect inputs were added together. For fuel, the assumption was made that the carbon footprint for mollusk and seaweed farming would be one-tenth compared to a situation where these farms would be separate, since aquafarmer workers and vessel boats required for the heavy monitoring of an fish farm can also be utilized for harvesting and monitoring of the seaweed and mollusks. The carbon sequestration of 1 kg of seaweed and mollusk were included.

4. Results & Discussion

4.1. Environmental impacts of different aquaculture systems

4.1.1. The Carbon footprint

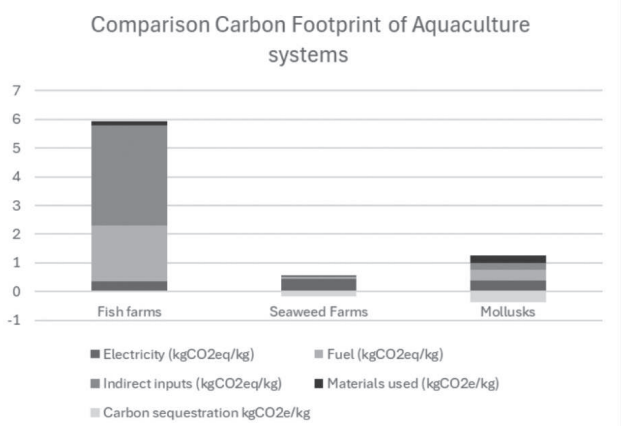

Figure 3: carbon footprint of the different aquaculture systems separately.

Figure 3 depicts clearly that, of the separate cultivation systems, fish farms have the highest carbon footprint (5.94 kgCO2e /kg), compared to seaweed (0.387 kg CO2e/kg) and mollusks (0.89 kgCO2e/kg). This is partly caused by the higher fuel consumption for fish farming. The LCA studies (Bujas et al, 2022; Garcia et al. 2019; Ayer & Tyemers) on the fish farms mentioned daily trips by vessels for constant monitoring. LCA studies about seaweed farms only mentioned the vessel trips for sowing of sporelings and harvesting of seaweed (Thomas et al., 2020; Li et al., 2024; Nilsson et al., 2024). mollusk farming also mentioned monitoring (Lourguioui et al., 2017; Turolla et al., 2020; Aubin et al., 2017), but the analysis shows that fuel costs are still significantly lower (figure 1).

The carbon footprint for electricity is fairly similar across the different aquafarm systems and has a small share in the total carbon footprint. In general electricity was mostly used for either cultivation of the juveniles or sporelings, and the further industrial processing. Electricity in fish farming was mostly used for the pre-growing of juveniles in controlled conditions (Garcia et al. 2019; Bujas et al., 2022). Further electricity costs originate from the preservation of fish (0.38 kWh/kg) (Murali et al., 2021). The electricity requirement for mollusks mostly originated from the pumping required for water purification in the pre-growing phase and the cleaning afterwards (Turolla et al., 2020; Aubin et al;2017). For seaweed farms, the only high direct energy costs originate from the energy required for drying of seaweed, which can reach up to 0.55 kWh/kg of seaweed (Nillsson et al, 2022). In total, this contributed on average to 95% of the electricity requirement. Without drying, seaweed even showed to have negative carbon emissions of -0.043 kgCO2e/kg.

Indirect inputs (fish feed) for fish farms are by far the highest contributor to the carbon footprint, with 3.48 kgCO2/kg fish. This is explained by a share of 97% of scope 3 emissions in total emissions (Biomar, 2023), which originate from the overall supply chain. Fish inputs need to be catched by vessels, soy cultivation could cause land use change emissions, the industrial processing is energy intensive, and the fish feed to be transported by ship. Especially considering that the used FCR in this study is conservative, the carbon footprint of fish feed in aquaculture is an important consideration.

In the Aruban context it is also important to look for options of aquaculture with little fresh water requirement. For Turolla, et al. (2020) with a predicted fresh water use of 0.3 m3/kg of clams, the carbon footprint of water alone contributed to 0.88 kgCO2e/kg of clams.

4.1.2. Eutrophication potential

Table 1: the Eutrophication potential of the different aquaculture systems.

Aquafarm type	Eutrophication potential (gPO4e/kg)
Fishfarming	83.17666667
Seaweed farming	-2.754308
mollusk farming	-1.276133333

Table 1 showcases the eutrophication of the different aquaculture systems. As expected, the eutrophication potential extracted from the LCA studies on fish farming is considerably high. The largest share for eutrophication originates from the cultivation and fish feed (Garcia et al., 2019; Ayer &Tyermers, 2008), since nutrient pollution is mostly produced by the feed and fish waste. The eutrophication abatement potential per kg of seaweed and mollusk produced is relatively low. Which entails that within an IMTA system the ratio of fish and lower trophic species for completely nullifying eutrophication must be at least higher than 83.17/2.75= 30.2 for seaweed and 83.17/1.278=65 for mollusks.

4.2. The carbon footprint of imported fish

Figure 4 shows that the carbon footprint of imported canned tuna varies between 11 to 11.9 kgCO2e/kg tuna for the different brands.

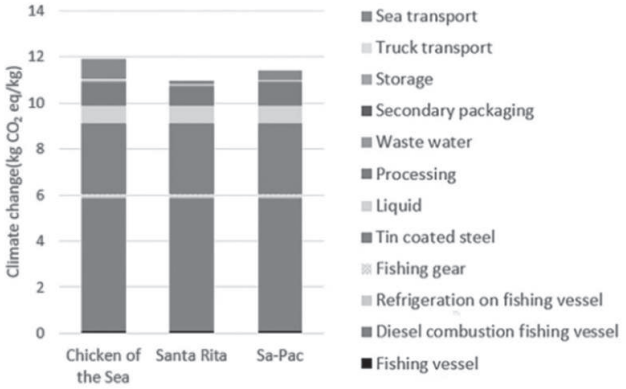

Figure 4: carbon footprint of imported canned tuna of three different brands as well as the shares of the different supply chain steps (De Vlieghere et al., 2023).

Unexpectedly, sea transport contributes little to the final carbon footprint (figure 3), while the majority stems from the diesel combustion required to catch the wild tuna (6 kgCO2e/kg of fish). In contrast, conventional fish farming, considering the full production supply chain and its inputs, already has a lower carbon footprint of 5.97 kgCO2e/kg, which offers a climate benefit compared to imports.

However, De Vlieghere et al. (2023) showed that the eutrophication potential (~0.62 mol Ne/kg = 0.26 PO4e/kg) is considerably lower compared to aquaculture fish production (83.2 gPO4e/kg), since little artificial nutrient waste is produced with catching wild fish, as fish live within their own natural habitats and feed waste is non-existent, reducing local eutrophication considerably. The highest contributor to eutrophication for imported tuna originated from fuel combustion (Vlieghere et al., 2023), which was negligible in the case of fish farms (Garcia et al., 2019; Ayer &Tyermers, 2008).

4.3. A comparison of the carbon footprint of the different scenarios of IMTA to conventional fish farming and imported tuna.

Since IMTA could be a method of mitigating eutrophication, four scenarios for carbon footprint calculations per kg of fish were developed for an IMTA farm in Aruba, based on the trade-offs which would be prioritized when utilizing IMTA. Specifically on the extent which Aruba would want to go in mitigating eutrophication from aquaculture practices. The carbon footprints will be calculated according to the cultivation of 1 kg of fish, because these footprints will be compared to the imported tuna.

- Scenario 1 constitutes the cultivation of 1 kg of fish, mollusk and seaweed. Within this scenario, eutrophication from fish farming would not be leveled out, but be reduced from 83.17 to 79.15 gPO4e/kg of fish produced. Fuel costs for seaweed and mollusks were multiplied by 0.1 since employees who travel to the farm to monitor and harvest the fish can also monitor and harvest the mollusks and seaweed.
- Scenario 2 entails completely leveling off eutrophication from fish farming by using a 50/50 ratio of mollusks and seaweed. Within this scenario, it was calculated that 83.17/(2.754+1.276)=20.62 kg of both mollusks and seaweed completely diminish the eutrophication caused by the production of fish. The extra energy requirements for cultivation of these extra kgs is included.
- Scenario 3 involves the sole cultivation of seaweed to abate eutrophication from 1 kg of fish. Seaweed is chosen since it is depicted to have a lower carbon footprint (figure 1) and eutrophication abatement potential (table 1). This would involve the need to cultivate 30.2 kg of seaweed per kg of fish.
- Scenario 4 also only incorporates the sole cultivation of seaweed. However, in this scenario drying of seaweed is not included, and seaweed cultivation is solely used for the purpose of eutrophication abatement and carbon sequestration. As mentioned before, excluding drying ensures that seaweed cultivation would entail negative carbon emissions of -0.042 kgCO2e/kg. However, this also means that seaweed would not be able to be used for commercial purposes, for which drying is a necessity. In this scenario also fresh water needed for cleaning is not included.

Within these scenarios the carbon footprints per kg of fish produced were calculated as showcased in figure 5.

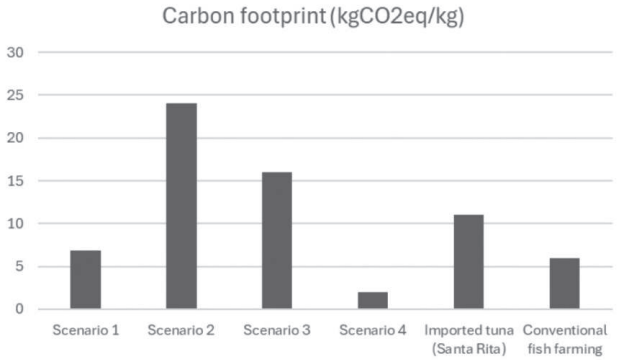

Figure 5: carbon footprints of the different scenarios, imported tuna and conventional fish farming

From the sole perspective of fish production and climate change, conventional fish farming with a carbon footprint of 5.97 kgCO2e would preferred over IMTA scenarios 1 (6.87 kgCO2e/kg), 2 (24.08 kgCO2e/kg) and 3 (15.98 kgCO2e/kg). However, the extra production of lower trophic species must not be overlooked in the described scenarios. It makes sense that with the extra production of seaweed and mollusks, it would induce extra carbon emissions. The total carbon footprint per kg of aquacultural product via IMTA in scenario 1 is solely 2.3 kg CO2e/kg. In general an IMTA system would be more efficient in energy use than cultivating all these species separately (figure 1),

which would constitute 7.23 kgCO2e/kg. Furthermore, the IMTA system has its considerable benefit of eutrophication reduction, which as emphasized in this research, is crucial in the case of Aruba. 1 kg of fish produced with IMTA system according to scenario 1, would also still have a lower carbon footprint 1 kg of imported tuna, even with the extra produced lower-trophic species, which does imply that producing fish locally would mitigate climate change compared to importing.

The necessity of reducing eutrophication in the nullifying eutrophication in scenario 2 and 3 does show to come with its cost with regard to the carbon footprint. While in scenario 1, eutrophication is only reduced by 2 gPO4eq, it does have a lower carbon footprint of 7.23 kgCO2e/kg of fish compared to scenario 2 and 3 with a carbon footprint of 24.1 kgCO2e/kg and 15.98 kgCO2e/kg. However, again the production of mollusks and seaweed must not be disregarded. Scenario 2 presents an extra cultivation of 20.6 kgs of mollusks and seaweed, with their own commercial purposes. Scenario 3 also involves an extra 30.2 kgs of seaweed. In scenario 4, where commercial value for the lower trophic species would be completely disregarded, the opposite to scenario 2 and 3 is shown as the extra seaweed cultivation can even reduce the carbon footprint to 1.99 kgCO2e/kg of produced fish, while at the same time completely leveling out eutrophication. Depending on which factors and species are given the most value, policy-makers can decide which kind of IMTA system they would prefer to develop. NGOs seeking to mitigate environmental impacts, might find scenario 4 the most feasible. While ministers might prefer the other scenarios, as the commercial purposes of the extractive species are utilized in scenario 1, 2 and 3.

5. Limitations

Within this section I will describe both the limitations of my study and an offshore IMTA system in Aruba.

5.1. Limitations of offshore IMTA

There are few current applications of IMTA in offshore oligotrophic conditions (nutrient-poor waters) , since its actual feasibility is still debated. Low ambient nutrients in oligotrophic waters may limit mollusk and seaweed growth, as fish feces alone may not be sufficient (Both et al., 2011). The actual eutrophication abatement by mollusks and seaweed in offshore conditions also might not be significant. In closed systems where the nutrient flow can be controlled from the fish species, the nutrient retention potential of IMTA (75%) is significantly higher than in offshore conditions where the nutrient flows are controlled by natural currents (50%) (Nederlof et al., 2019). Despite its lower suitability in open systems, an offshore IMTA system still shows to increase the nitrogen retention potential by 7-37% (Nederlof et al., 2021)

The most suitable method of placement of extractive species in offshore conditions for effective nutrient retention is still under discussion. Nutrient dispersal in open systems is largely vertical (Filgueira et al., 2017), placing mussels below or just up-current of fish cages may optimize uptake, although local suitability must be studied first. On the other hand, other studies suggest that large areas for extractive species further up current must be utilized instead as nutrients get diluted by the strong currents (Nederlof et al., 2021).

Another important challenge is that both farming systems and species must endure the harsh hydraulic conditions of offshore systems (Buck et al., 2018). The acceleration caused by breaking waves and swell may cause considerable stress to the cultured organisms (Buck et al., 2018). There are already numerous examples of successful open water fish cage systems by placing the fish deeper in the water to reduce hydraulic stress (Buck et al., 2018), but offshore farming of extractive species is still limited. However, technology and methods are being researched and are improving. Large kelp species show to be most suitable

(Buck et al., 2018). Farm designs of longline macroalgal rig with a horizontal fix line and vertical seed lines hanging perpendicular to the backbone have proven to withstand winds up to 62 m/s and wave heights of 7-8 m without any damage (Buck et al., 2018).

Concerning the significant challenges and limitations of offshore IMTA, it is questionable whether Aruba, with its limited capacity and knowledge on aquaculture, should be a pioneer in the implementation of an offshore IMTA system. In a future scenario the technical feasibility and actual eutrophication abatement potential first must be properly assessed via small-scale applications before upscaling.

5.2. Limitations of my own study

As outlined in the methodology, there were little LCA studies available on offshore aquaculture, let alone offshore IMTA in the tropics. This ensured that I had to use LCA studies of the species separately to be able to assess the carbon footprint of local fish production in Aruba, also including LCA-studies of aquacultural species from colder regions in the world. The electricity requirement could differ between these LCA studies and an actual aquafarm in Aruba. Furthermore, the preferred native species for local aquaculture might require other treatment in the pre and post cultivation, which could also alter energy requirements. Next to that, the collected LCA studies did not all explicitly mention the distance of the aquafarm to the coast. In these cases, the location had to be estimated by locating the aquafarms in QGIS and measuring the distance, to be able to adjust the fuel costs according to an aquafarm in Aruba. Furthermore, some LCA studies did not include post process energy requirements, which ensured that these energy requirements were duplicated from other LCA studies. The nutrient uptake by mollusks and seaweed were also not considered by all studies, so these values also had to be copied from other studies. This was also a limitation especially considering that species differ in their nutrient uptake. A better approach might have been to develop an LCA study myself, but this still would entail the problem of limited data availability. Lastly, I was only able to compare the carbon footprint of local fish production with imported tuna, limiting the possibility for a more extensive assessment. So while this research was far from perfect, I hope that it still could provide a base framework for future research on IMTA in the Caribbean.

6. Conclusion

This study has examined the environmental implications of aquafarming on Aruba, focusing especially on its eutrophication potentials and carbon footprint. Although aquafarming on Aruba has a great potential to improve food security and economic diversification on the island, it does come with its ecological risk. Especially with the current fragile state of the marine ecosystem in Aruba. Additional nutrient pollution could be detrimental for photosynthesis for corals. Carbon emissions could further enhance ocean acidification and limit reef building. Escaped species could become invasive and disrupt the marine ecosystem. For a potential future of intensive aquaculture on the island, these risks must be properly assessed according to the precautionary principle; the project must show to have little environmental impacts before its actual implementation (NGO, personal communications.)

An IMTA system which integrates fish farming with seaweed and mollusk cultivation and mimicking natural ecosystems, may mitigate these ecological risks. Since seaweed and mollusks actively absorb excessive nutrients from fish production, while also offering possibilities for carbon sequestration. A key finding from this study indicated that fish produced via an IMTA system have a lower carbon footprint (7.23 kgCO2eq/kg) compared to imported fish (11-11.9 kgCO2e/kg), while also providing additional seaweed and mollusk which could be used for commercial use. Furthermore, it indicated that in a

scenario 4 with complete abatement of eutrophication where seaweed would be used for the sole purpose of its ecosystem services. It could even halve the carbon footprint (2.015 kgCO2eq/kg) compared to conventional fish farming (5.97 kgCO2eq/kg). For that reason, it could be a promising option for future aquaculture production on the island.

Since there are few current applications of a far offshore IMTA system in the tropics, Aruba must be aware of its practical challenges and risks associated with utilizing a novel system. Therefore, further research is necessary to investigate these challenges specifically for Aruba, considering its unique hydrological and climate conditions, limited knowledge on aquafarming.

On a final note, before expanding aquaculture into these waters, we must be aware of the implications of treating nature as a resource that provides for us and what this has meant for the current state of our planet. As we are embarking on the journey of aquaculture, we must wonder, are we able to use the ocean's resources carefully, or whether we need to leave the ocean untouched.

References

- Abdou, K., Aubin, J., Romdhane, M. S., Loc'h, F. L., & Lasram, F. B. R. (2017). Environmental assessment of seabass (Dicentrarchus labrax) and seabream (Sparus aurata) farming from a life cycle perspective: A case study of a Tunisian aquaculture farm. Aquaculture, 471, 204–212. https://doi.org/10.1016/j.aquaculture.2017.01.019
- Altieri, A. H., Harrison, S. B., Seemann, J., Collin, R., Diaz, R. J., & Knowlton, N. (2017). Tropical dead zones and mass mortalities on coral reefs. Proceedings Of The National Academy Of Sciences, 114(14), 3660–3665. https://doi.org/10.1073/pnas.1621517114
- Åsøy, L., Zhang, H., & Nerheim, A. R. (2024). Specific Fuel Oil Consumption Models for Simulating Energy Consumption of Wellboats. Modeling Identification And Control A Norwegian Research Bulletin, 45(1), 1–14. https://doi.org/10.4173/mic.2024.1.1
- Aubin, J., Fontaine, C., Callier, M., & D'orbcastel, E. R. (2017). Blue mussel (Mytilus edulis) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. The International Journal Of Life Cycle Assessment, 23(5), 1030–1041. https://doi.org/10.1007/s11367-017-1403-y
- Ayer, N. W., & Tyedmers, P. H. (2008). Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. Journal Of Cleaner Production, 17(3), 362–373. https://doi.org/10.1016/j.jclepro.2008.08.002
- Blok, K., & Nieuwlaar, E. (2020). Introduction to Energy Analysis. In Routledge eBooks. https://doi.org/10.4324/9781003003571
- Both, A., Parrish, C. C., Penney, R. W., & Thompson, R. J. (2011). Lipid composition of Mytilus edulis reared on organic waste from aGadus morhuaaquaculture facility. Aquatic Living Resources, 24(3), 295–301. https://doi.org/10.1051/alr/2011138
- Boyer, M., Horton, J., & Millán, M. F. (2020). Building

Resilience in Aruba's Food Security During the COVID-19 Pandemic and Beyond. World Bank.

- Brown, B. E., Dunne, R. P., Somerfield, P. J., Edwards, A. J., Simons, W. J. F., Phongsuwan, N., Putchim, L., Anderson, L., & Naeije, M. C. (2019). Long-term impacts of rising sea temperature and sea level on shallow water coral communities over a ~40 year period. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-019-45188-x
- Bujas, T., Koričan, M., Vukić, M., Soldo, V., Vladimir, N., & Fan, A. (2022). Review of Energy Consumption by the Fish Farming and Processing Industry in Croatia and the Potential for Zero-Emissions Aquaculture. Energies, 15(21), 8197. https://doi.org/10.3390/en15218197
- Castellanos-Galindo, G. A., Chong-Montenegro, C., Baos E, R. A., Zapata, L. A., Tompkins, P., Graham, R. T., & Craig, M. (2018). Using landing statistics and fishers' traditional ecological knowledge to assess conservation threats to Pacific goliath grouper in Colombia. Aquatic Conservation: Marine and Freshwater Ecosystems, 28(2), 305–314. https://doi.org/10.1002/aqc.2871
- Central Bureau of Statistics Aruba (2019). Income and Expenditure Survey 2016. https://cbs.aw/wp/index.php/2019/04/04/income-expenditure-survey-2016/
- Costello, C., Cao, L., Gelcich, S., Cisneros-Mata, M. Á., Free, C. M., Froehlich, H. E., Golden, C. D., Ishimura, G., Maier, J., Macadam-Somer, I., Mangin, T., Melnychuk, M. C., Miyahara, M., de Moor, C. L., Naylor, R., Nøstbakken, L., Ojea, E., O'Reilly, E., Parma, A. M., & Plantinga, A. J. (2020). The future of food from the sea. Nature, 588(7836), 95–100. https://doi.org/10.1038/s41586-020-2616-y
- De Vlieghere, A., Van Veghel, A. S., & Geeraerd, A. (2023). Life cycle assessment of importing canned tuna into Aruba through different supply chains, in varying can sizes and in oils, brine or tomato sauce. The International Journal Of Life Cycle Assessment, 28(11), 1577–1589. https://doi.org/10.1007/s11367-023-02207-4
- Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A. (2008). Ocean acidification: the other CO2 problem. Annual Review Of Marine Science, 1(1), 169–192. https://doi.org/10.1146/annurev.marine.010908.163834
- Feng, J., Sun, L., & Yan, J. (2022). Carbon sequestration via shellfish farming: A potential negative emissions technology. Renewable And Sustainable Energy Reviews, 171, 113018. https://doi.org/10.1016/j.rser.2022.113018
- Filgueira, R., Guyondet, T., Reid, G., Grant, J., & Cranford, P. (2017). Vertical particle fluxes dominate integrated multi-trophic aquaculture (IMTA) sites: implications for shellfish-finfish synergy. Aquaculture Environment Interactions, 9, 127–143. https://doi.org/10.3354/aei00218
- Froehlich, H. E., Runge, C. A., Gentry, R. R., Gaines, S. D., & Halpern, B. S. (2018). Comparative terrestrial feed and land use of an aquaculture-dominant world. Proceedings Of The National Academy Of Sciences, 115(20), 5295–5300. https://doi.org/10.1073/pnas.1801692115
- García, B. G., Jiménez, C. R., Aguado-Giménez, F., & García, J. G. (2019). Life Cycle Assessment of Seabass (Dicentrarchus labrax) Produced in Offshore Fish Farms: Variability and Multiple Regression Analysis. Sustainability, 11(13), 3523. https://doi.org/10.3390/su11133523
- Garlock, T., Asche, F., Anderson, J., Ceballos-Concha, A., Love, D. C., Osmundsen, T. C., & Pincinato, R. B. M. (2022). Aquaculture: The missing contributor in the food security agenda. Global Food Security, 32, 100620. https://doi.org/10.1016/j.gfs.2022.100620
- Gephart, J. A., Henriksson, P. J. G., Parker, R. W. R., Shepon, A., Gorospe, K. D., Bergman, K., Eshel, G., Golden, C. D., Halpern, B. S., Hornborg, S., Jonell, M., Metian, M., Mifflin, K., Newton, R., Tyedmers, P., Zhang, W., Ziegler, F., & Troell, M. (2021).

Environmental performance of blue foods. Nature, 597(7876), 360–365. https://doi.org/10.1038/s41586-021-03889-2

- Guinee, J. B. (2002). Handbook on life cycle assessment operational guide to the ISO standards. The International Journal Of Life Cycle Assessment, 7(5). https://doi.org/10.1007/bf02978897
- Hala, A. F., Chougule, K., Cunha, M. E., Caria, M. M., Oliveira, I., Bradley, T., Forbes, J., & Galileu, S. L. (2024). Life cycle assessment of integrated multi-trophic aquaculture: A review on methodology and challenges for its sustainability evaluation. Aquaculture, 741035–741035. https://doi.org/10.1016/j.aquaculture.2024.741035
- Hall, C. A., Lambert, J. G., & Balogh, S. B. (2013). EROI of different fuels and the implications for society. Energy Policy, 64, 141–152. https://doi.org/10.1016/j.enpol.2013.05.049
- Herrero, M., Wirsenius, S., Henderson, B., Rigolot, C., Thornton, P., Havlík, P., De Boer, I., & Gerber, P. J. (2015). Livestock and the Environment: What Have We Learned in the Past Decade? Annual Review Of Environment And Resources, 40(1), 177–202. https://doi.org/10.1146/annurev-environ-031113-093503
- Holmer, M. & Kristensen, E. (1992). Impact of marine fish cage farming on metabolism and sulfate reduction of underlying sediments. Mar. Ecol. Prog. Ser. 80, 191-201.
- Hughes, T. P., Barnes, M. L., Bellwood, D. R., Cinner, J. E., Cumming, G. S., Jackson, J. B. C., Kleypas, J., van de Leemput, I. A., Lough, J. M., Morrison, T. H., Palumbi, S. R., van Nes, E. H., & Scheffer, M. (2017). Coral reefs in the Anthropocene. Nature, 546(7656), 82–90. https://doi.org/10.1038/nature22901
- IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157896
- Jackson, J. B. C., Donovan, M. K., Cramer, K. L., & Lam, V. V. (Eds.). (2014). Status and Trends of Caribbean Coral Reefs: 1970–2012. Global Coral Reef Monitoring Network, IUCN.
- Jansen, M. D., Mohan, C. V., & Gironès, O. P. (2019). World Bank Case Studies: Biosecurity in Aquaculture—Examples of Innovative and Effective Approaches. The World Bank Group.
- Innovasea. (2024, 11 juni). Petros Gains Approval for Aruba's First Ocean-Based Fish Farm. https://www.innovasea.com/news/innovasea-helps-petros-secure-approval-for-aruba-fish-farm/
- Jiang, Z., Liu, J., Li, S., Chen, Y., Du, P., Zhu, Y., Liao, Y., Chen, Q., Shou, L., Yan, X., Zeng, J., & Chen, J. (2019). Kelp cultivation effectively improves water quality and regulates phytoplankton community in a turbid, highly eutrophic bay. The Science Of The Total Environment, 707, 135561. https://doi.org/10.1016/j.scitotenv.2019.135561
- Li, J., Bergman, K., Thomas, J. E., Gao, Y., & Gröndahl, F. (2023). Life Cycle Assessment of a large commercial kelp farm in Shandong, China. The Science Of The Total Environment, 903, 166861. https://doi.org/10.1016/j.scitotenv.2023.166861
- Lian, Y., Wang, R., Zheng, J., Chen, W., Chang, L., Li, C., & Yim, S. C. (2023). Carbon sequestration assessment and analysis in the whole life cycle of seaweed. Environmental Research Letters, 18(7), 074013. https://doi.org/10.1088/1748-9326/acdae9
- Lourguioui, H., Brigolin, D., Boulahdid, M., & Pastres, R. (2017). A perspective for reducing environmental impacts of mussel culture in Algeria. The International Journal Of Life Cycle Assessment, 22(8), 1266–1277. https://doi.org/10.1007/s11367-017-1261-7
- Mekonnen, M. M., & Hoekstra, A. Y. (2012). A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems, 15(3), 401–415. https://doi.org/10.1007/s10021-011-9517-8
- Messagie, M., Mertens, J., Oliveira, L., Rangaraju, S.,

Sanfelix, J., Coosemans, T., Van Mierlo, J., & Macharis, C. (2014). The hourly life cycle carbon footprint of electricity generation in Belgium, bringing a temporal resolution in life cycle assessment. Applied Energy, 134, 469–476. https://doi.org/10.1016/j.apenergy.2014.08.071

- Mijts, E., Singh, S., & Martin del Campo, F. (2023). The resource (in) sufficiency of the Caribbean: analyzing socio-metabolic risks (SMR) of water, energy, and food. Frontiers. Clim. 5:1085740. https://doi.org/10.3389/fclim.2023.1085740
- Murali, S., Krishnan, V. S., Amulya, P., Alfiya, P., Delfiya, D. A., & Samuel, M. P. (2021). Energy and water consumption pattern in seafood processing industries and its optimization methodologies. Cleaner Engineering And Technology, 4, 100242. https://doi.org/10.1016/j.clet.2021.100242
- Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., & Troell, M. (2000). Effect of aquaculture on world fish supplies. Nature, 405(6790), 1017–1024. https://doi.org/10.1038/35016500
- Nilsson, A. E., Bergman, K., Barrio, L. P. G., Cabral, E. M., & Tiwari, B. K. (2022). Life cycle assessment of a seaweed-based biorefinery concept for production of food, materials, and energy. Algal Research, 65, 102725. https://doi.org/10.1016/j.algal.2022.102725
- Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., ... & Yool, A. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature, 437(7059), 681-686.
- Pessarrodona, A., Howard, J., Pidgeon, E., Wernberg, T., & Filbee-Dexter, K. (2024). Carbon removal and climate change mitigation by seaweed farming: A state of knowledge review. The Science Of The Total Environment, 918, 170525. https://doi.org/10.1016/j.scitotenv.2024.170525
- Petersen, J. K., Holmer, M., Termansen, M., & Hasler, B. (2018). Nutrient Extraction Through Bivalves. Goods and Services of Marine Bivalves, 179–208. https://doi.org/10.1007/978-3-319-96776-9_10
- Petersen, J. K., Hasler, B., Timmermann, K., et al. (2014). Mussels as a tool for mitigation in the marine environment. Mar Pollut Bull 82:137–143
- Salimi, P. A., Creed, J. C., Esch, M. M., Fenner, D., Jaafar, Z., Levesque, J. C., Montgomery, A. D., Salimi, M. A., Edward, J. K. P., Raj, K. D., & Sweet, M. (2021). A review of the diversity and impact of invasive non-native species in tropical marine ecosystems. Marine Biodiversity Records, 14(1). https://doi.org/10.1186/s41200-021-00206-8
- Salud Deudero, Tor, A., Alomar, C., Maria, J., Piluca Sarriera, & Blanco, A. (2011). Integrated Multitrophic Aquaculture: Filter Feeders Bivalves as Efficient Reducers of Wastes Derived from Coastal Aquaculture Assessed with Stable Isotope Analyses. InTech EBooks. https://doi.org/10.5772/28457
- Summa, D., Turolla, E., Lanzoni, M., Tamisari, E., Castaldelli, G., & Tamburini, E. (2023). Life Cycle Assessment (LCA) of Two Different Oyster (Crassostrea gigas) Farming Strategies in the Sacca di Goro, Northern Adriatic Sea, Italy. Resources, 12(6), 62. https://doi.org/10.3390/resources12060062
- Tamburini, E., Turolla, E., Fano, E. A., & Castaldelli, G. (2020). Sustainability of Mussel (Mytilus Galloprovincialis) Farming in the Po River Delta, Northern Italy, Based on a Life Cycle Assessment Approach. Sustainability, 12(9), 3814. https://doi.org/10.3390/su12093814
- Thomas, J.-E., Ribeiro, M. S., Potting, J., Cervin, G., Nylund, G. M., Olsson, J., Albers, E., Undeland, I., Pavia, H., & Gröndahl, F. (2020). A comparative environmental life cycle assessment of hatchery, cultivation, and preservation of the kelp Saccharina latissima. ICES Journal Of Marine Science, 78(1), 451–467. https://doi.org/10.1093/icesjms/fsaa112
- Troell, M., Metian, M., Beveridge, M., Verdegem, M., & Deutsch, L. (2014). Comment on 'Water footprint

of marine protein consumption—aquaculture's link to agriculture'. Environmental Research Letters, 9(10), 109001. https://doi.org/10.1088/1748-9326/9/10/109001

- Troell, M., Naylor, R. L., Metian, M., Beveridge, M., Tyedmers, P. H., Folke, C., Arrow, K. J., Barrett, S., Crépin, A. S., Ehrlich, P. R., Gren, Å., Kautsky, N., Levin, S. A., Nyborg, K., Österblom, H., Polasky, S., Scheffer, M., Steneck, R. S., Walker, B. H., & Xepapadeas, A. (2014). Does aquaculture add resilience to the global food system? Proceedings of the National Academy of Sciences, 111(37), 13257–13263. https://doi.org/10.1073/pnas.1404067111
- Wang, Q., Sun, X., Lin, S., Dong, Y., Shen, H., He, Z., Luo, H., Zou, L., Chung, I. K., & Yang, Y. (2025). Large-scale seaweed cultivation as a nature solution for carbon-negative economy and restorative environmental stewardship: Lessons from China. Renewable and Sustainable Energy Reviews, 207, 114954. https://doi.org/10.1016/j.rser.2024.114954
- WEB. (2023). WEB Aruba N.V. | Water- en Energiebedrijf Aruba N.V. https://webaruba.com/company/calculate-your-emissions
- Welch, A. W., Knapp, A. N., Tourky, S. E., Daughtery, Z., Hitchcock, G., & Benetti, D. (2019). The nutrient footprint of a submerged-cage offshore aquaculture facility located in the tropical Caribbean. Journal Of The World Aquaculture Society, 50(2), 299–316. https://doi.org/10.1111/jwas.12593
- Wu, R. S. S. (1995). The environmental impact of marine fish culture: Towards a sustainable future. Marine Pollution Bulletin, 31(4), 159–166. https://doi.org/10.1016/0025-326X(95)00100-2
- Wu, R., Lam, K., MacKay, D., Lau, T., & Yam, V. (1994). Impact of marine fish farming on water quality and bottom sediment: A case study in the sub-tropical environment. Marine Environmental Research, 38(2), 115–145. https://doi.org/10.1016/0141-1136(94)90004-3

Sofia Acquilino, Utrecht University

Aruba, A rollercoaster of emotions.

They call it "One Happy Island", but I must say that I experienced all kinds of emotions in Aruba" the joy of meeting new people, the fear of getting out of my comfort zone, the peacefulness of the sunsets spent at the beach with pizza and friends, the anxiety before my first interview, the inspiration when listening to other's perspectives, the confusion when I first heard the word "eutrophication", the amusement during the nights out, the surprise of realizing that research does not always go as expected, the vulnerability when I realized that these people here were becoming family, the hope that this project can contribute, even if just a tiny bit, in making a more equitable and inclusive world, the eternal respect for all the people that have been actively contributing to the life in Aruba, from Eric and all UA the staff welcomed us, to Dianne and Val from the animal shelter, to Jean and the ABV staff who supported us when blasting music a bit too loud a bit too late, and to Jocelyn for having introduced me to this new, marvellous reality and accompanying me in this journey.

These months in Aruba have been a rollercoaster that I would do all over again. They call it a 'small island', but Aruba is a lot. A lot of languages, a lot of culture, a lot of music, and a lot of biodiversity, and especially of roundabouts. And yes, I did not always know which car had the priority, but these people here always helped me because as we say, we are all in this together.

I am very grateful for the people that I met during this journey. Starting from the Aruban students welcomed us with a smile and shared with us their precious knowledge on where to find good food trucks on the island. Grazie Sofia, for being an amazing housemate and friend, with whom I shared all kinds of moments, ranging from linguistic endings to watching series and debating on the best shape

of pasta. Thank you, guys, for playing Just Dance with me even during stressful deadlines, Lisa, for the beautiful conversations full of laughs and emotions, Zaza for always having a speaker to add a sound to our memories, and Plym for always being there, even just to tell me that fish is super important for the ecosystem. Thank you all GSS students for teaching me how to think beyond my Humanities major bubble, and that the world is a better place if everybody, not just humans, is considered.

'A curse and a blessing' Investigating Monolingual Ideologies in the Multilingual Realities of Aruba

Sofia Acquilino

1. Introduction

With more than 6.800 languages, the world is multilingual. Each language offers a different perspective on human experience and the world, embodying its speech community's history, culture, and system of values (Ouen et al., 2003). Languages are valuable legacies passed down through the generations and deserve to be respected, preserved, and celebrated (Dijkhoff et al., 2010).

Aruba, a small island state in the Caribbean, is a vibrant representation of rich linguistic diversity in a community. With four main languages present on the island – Papiamento, Dutch, English, and Spanish – different speech varieties coexist in the same social space, being embedded in their socio-economic, political, and historical realities (Bourdieu, 1991). Although Papiamento is the native language of 68% of Aruba's population, the colonial ties with the Kingdom of the Netherlands have positioned Dutch as the main language in Aruban education (Mijts, 2021). Alongside this, the growing 'touristification' of the island, has made both Dutch and English especially dominant in formal domains such as education, business, and government.

Just like 40% of the world's children, most Aruban students have limited or no access to education in their home language which is, as advocated by UNESCO, one of the main issues that hinder quality education, inclusive development, and socio-economic mobility (Mijts, 2021). These dynamics create the conditions for social injustice, as those who refuse or are unable to conform to the dominant language(s) have limited access to resources (Blackledge, 2000).

As language development and use are related to beliefs and opinions (Canese, 2018; Wodak, 2007), with this study, I explore how individuals in Aruba feel about multilingualism in their community and broader society. These beliefs often reflect underlying power dynamics that influence how language is regulated and valued within different communities. In this way, language ideologies, which are deeply rooted beliefs about language, play a key role in shaping language policies. These policies can both reflect and reinforce dominant ideologies, influencing which languages are promoted or marginalized (Canese, 2018). Language ideologies, then, function as frameworks through which users rationalize or justify the perceived language structure and use in society (Albury, 2020). As Verschueren (2012) notes, ideologies are assumed to be 'commonsensical' within a community. At the same time, I acknowledge the existence of a plurality of interconnectedness 'realities' or worlds, where different people relate to language, and the world, in significantly different ways (Zúñiga, 2025).

In the present study, I investigate the presence of monolingual ideologies, which favor the use of one dominant language, in the multilingual realities of Aruba, and how they influence

access to educational and professional opportunities in the community. By adding an intergenerational dimension to the research, I also aim to understand whether there is an ongoing generational change in the dominance of monolingual ideologies in the Aruban society.

In this paper, I introduce the background literature describing the multilingual realities of Aruba, monolingual and multilingual language ideologies, and the concept of language as capital, reflecting on languages as resources to access opportunities. Moreover, the importance of looking at intergenerational changes in language ideologies is discussed, followed by their relevance in informing language policies. The background literature is followed by the methodology section, and I conclude by presenting the preliminary results of the ongoing study. In the upcoming weeks, I will conduct more fieldwork on Aruba, and the full study will be reported on in my homonymous thesis.

This project is only possible thanks to the collaboration of the Aruban community, whose empirical knowledge and expertise helped me throughout the entire research process. Through a Community-Engaged Research approach, I combine academic knowledge from multiple academic disciplines (sociolinguistics, sociology, and politics) with the real-life experiences of the Aruban people. In the different phases of the research, the Aruban community was involved, giving their input on the initial project idea, helping develop the questionnaires, and sharing their perspectives during the interviews. With this approach, I also aim to highlight the fundamental role of the community's perspectives in the development, implementation, and reception of language policies (Mijts, 2021). In this way, this research reflects not just academic inquiry, but the realities voiced by those directly affected by language policies in Aruba.

2. Positionality Statement

I am a 21-year-old Italian woman from the low-middle socioeconomic class, and I am enrolled at Utrecht University, focusing on Linguistics, Psychology, and Sociology. My positionality shapes not only my research topic but also how I interact with participants and interpret data. I was born in Sicily, a Southern Italian Island where the local language is often marginalized by Standard Italian, making me feel insecure about my accent and grammar, especially in formal contexts such as education.

Considering the limited opportunities on my island, I felt the need to move abroad at 16 to continue my studies in France, and then to the Netherlands, where learning their languages has played an important role in integrating into their society. As Anzaldua (1987) said, *'I am my language, and until I can't take pride in my language, I cannot take pride in myself'*, so I am still trying to find a way to embrace all the languages I carry without shame or hesitation. One way of fighting that pride is by advocating for the rights of minority languages, and in the case of this study, in Aruba.

I recognize that my position within academia grants me access to tools and legitimacy often denied to the very communities whose voices need to be heard. At the same time, I am aware that my perspective on languages in Aruba is limited. While aspects of my experience might resonate, they can never fully capture the depth and complexity of the multilingual realities in Aruba. That is why listening closely, with humility, openness, and respect, is central to my approach.

3. Background Literature

3.1. Languages in the Social Realities of Aruba

The colonial history of Aruba and its economic development have resulted in a rich linguistic melting pot in which Papiamento, Dutch, English, and Spanish play a key role in the different domains of its society (Mijts, 2021). Most of the population born in Aruba considers Papiamento as their home language (68%), followed by Spanish (14%), English (8%), and Dutch (6%) (Mijts, 2021). While Papiamento and Dutch have been the official languages of the island

since 2003, Dutch is dominant in the Aruban education, governance, and judiciary (Mijts, 2021).

'Creole languages', such as Papiamento in Aruba, are described as speech varieties that emerged during the relatively abrupt contact between groups of speakers of different languages (DeGraff, 2009). Papiamento developed through contact between the Indigenous Arawak people, enslaved Western African people, and European colonizers (DeGraff, 2009). In the Caribbean, Creole languages are common. However, their legitimacy as valued sources for education and other formal settings is still questioned. Dijkhoff et al. (2010) describe Aruba's 'language problem' as a situation where both Papiamento and Dutch are used in the society, but Dutch and the influence of the European Netherlands, dominate the educational policy.

3.2. Describing Language Ideologies

A common working assumption in theoretical linguistic theory is that languages are equal, autonomous, and homogeneous entities. This assumption was criticized by Bourdieu who described it as the 'illusion of linguistic communism' since languages are embedded in their socio-economic, political, and historical realities (Bourdieu, 1991). Beliefs about languages and how/where/why different languages should be used, together with their status, are perceived through social filters (Albury, 2020). In this sense, the societal conflict over languages is not a debate over linguistic codes, but about language as a worldview, representing perspectives or, in other words, ideological positions (Canese, 2018).

Language ideologies can be defined as 'sets of beliefs about language articulated by users as rationalization or justification of perceived language structure and use' (Albury, 2020). As described by Spolsky, 'language ideology is language policy with the manager left out, indicating what people think should be done' (Spolsky, 2008, cited in Mijts, 2021). Studying language ideologies bridges linguistic and social theory, considering language use, attitudes, and beliefs while considering power dynamics leading to social inequality (Blackledge, 2000).
In this section, I explore two contrasting ideologies: monolingual ideologies, which tend to prioritize a single dominant language, often at the expense of others, and multilingual ideologies, which value linguistic diversity and fluid language use.

Language ideologies and attitudes are not the same constructs: ideologies are socially constructed and refer to 'how things should function in society', whereas attitudes towards language are a person's evaluation of a specific language matter (Albury, 2020). Attitudes can sometimes be traced back to systematic language ideologies, and while they can be incongruent, they can still inform each other. For example, when presented with the stimulus 'multilingualism' in a specific context, a person who carries monolingual ideologies might respond that multilingualism in that domain is undesirable or inadequate (Albury, 2020). However, a person might hold multilingual ideologies that support the preservation of minority languages, while not actively manifesting those ideologies in individual attitudes (Albury, 2020).

3.2.1. Monolingual Ideologies: One Language, One People

Western perspectives on language generally assume that it is 'natural' and 'normal' that one single language represents a people or a nation-state: the 'monolingual assumption' (Blackledge, 2000). However, this perspective emerged only with the formation of 'nation-states' in Europe, when the need to adopt a homogeneous, official common language became increasingly important. The standardization of a few of the spoken languages, selected by the ruling elite of the European nations, was the 'fatality of human linguistic diversity'.

Dijkhoff et al. (2010) found that in Aruba, Papiamento is often perceived as a language of low prestige, and it is often seen more as a 'dialect' than a language itself. In contrast, Dutch is perceived as having a higher status and found more suitable for formal contexts such as education. These findings hint at the broader colonial ideologies that often tie power and authority to a single, dominant, colonial language. Monolingual ideologies often frame Caribbean languages as 'incomplete', inadequate', or 'incorrect', in contrast to the European languages (Albury, 2021; Mijts, 2021). This assumption can be particularly detrimental in multilingual contexts such as Aruba, where students are assessed according to the monolingual standards of European Dutch education, sometimes making them feel that their home languages are 'inferior' or 'not perfect' (Sollie, 2015).

In multilingual societies like Aruba, the act of code-switching, which is the alternation between languages within a discourse, is perceived as normal (Lo-Fo-Sang, 2022). This phenomenon happens in the classroom too, where Aruban students can use the languages available in their repertoires to convey meaning to their professors and fellow students. However, the current language policies, together with the dominant ideology, can promote the normative idea of 'linguistic purism', where only one 'pure', 'unpolluted' language should be used in the educational setting (Baioud et al., 2022). As Martinez et al. (2015) point out, the role of teachers in promoting certain ideologies is crucial, as their perspective contributes to determining students' ideas and beliefs toward multilingualism. Nevertheless, linguistic purism can also be part of the resistance to colonial oppression, rejecting the mixture of the minority language with the dominant colonial language(s). In Aruba, no study was found yet describing the monolingual ideology promoting 'Papiamento Puro', a term used to describe the use of the language without mixing with other standardized languages such as Dutch or Spanish, but also English, considering the latter's predominant role on the island and in the Western world in general (Baioud et al., 2022).

3.2.2. Multilingual Ideologies Advocating for Linguistic Diversity

The term 'multilingualism' refers to 'the ability to speak, at some level, more than one language' (Han, 2011). In contrast to monolingual ideologies, 'multilingual ideologies' recognize the value of linguistic diversity and encourage the use of multiple languages in society. Contrary to the monolingual ideologies, very little academic literature has been dedicated to them. However, it is widely recognized that monolingual countries are the exception, not the rule (Ouen et al., 2003). By interpreting multilingualism as a natural 'unmarked' aspect of society, the linguistic order assumed in monolingual ideologies is challenged (Albury, 2020). Through this perspective, individuals are recognized as multilingual even when having diverse degrees of proficiency and use between the different languages (Han, 2011).

When considering the multilingual realities around the world, the concept of linguistic diversity is essential. Linguistic diversity not only refers to the presence of more than 6.000 languages in the world, but also considers each language as carrying its knowledge, history, and worldview. Linguistic diversity can be threatened if it has few users and a weak political status, or when it is not transmitted through education and across generations (Skutnabb-Kangas, 2003). As Dijkoff et al. (2018) point out, Papiamento is the language of the majority in Aruba, and it should be protected and cherished to ensure its social preservation and growth in social status, to extend its vocabulary and domains of use.

According to multilingual ideologies, humans engage in 'languaging': when speaking, we maintain, innovate, modify, alter, and create new linguistic forms based on our social relations, which creates linguistic diversity in space and time (Bastardas-Boadas, 2019). Suppressing this process through purist or standardized norms undermines the vitality of languages and limits their growth in everyday and institutional spaces (Albury, 2020). This is particularly

problematic in educational settings, where speakers of minority languages are often discouraged from embracing hybrid linguistic practices such as code-switching (Han, 2011).

The Aruban population is rich in linguistic resources and potential, and yet, still, a lot needs to be done to protect, maintain, and actively cultivate to make the most out of it (Faraclas et al., 2022). Faraclas et al. (2022) explored the multilingual situation in Bonaire, describing both the challenges and the hopes for more inclusive language policies and practices on the island. The multilingual realities of the island are something that the people can be proud of, although it is still being discouraged by institutional practices. In multilingual societies, when one language is imposed on the people, the other languages are implicitly excluded, and so are their speakers (Mijts, 2021). Even when speaking the dominant language, it is not obvious that the speakers will be able to access the information. For instance, promoting multilingual ideologies and practices is a step forward in societal and linguistic inclusion. According to previous studies in Bonaire, people expressed generally positive attitudes towards Papiamento Dutch, Spanish, and English, especially when thinking of multilingualism to promote more inclusivity (Faraclas et al., 2022). Considering the historical and linguistic similarities between Bonaire and Aruba, similar results are expected.

3.3. Language as Capital

Monolingual ideologies do not only create a challenge for students when it comes to developing skills in their home language, but they can also play a key role in future opportunities (Farr et al., 2011). When discussing language in society, Bourdieu (1991) describes it as capital, which is a form of power that can produce some kind of profit. According to Bourdieu (1991), society functions as a 'linguistic marketplace', where some ways of speaking are more valued than others, and people 'compete' to have the kind of language that brings the most social or economic benefits (Kiramba et al., 2023).

This creates the illusion that competence in standard languages (such as English or Dutch) is a product that individuals can 'possess' or 'lack', and those who do not acquire it are seen as not choosing to (Farr et al., 2011). Fluency in the standard language assumes an instrumental value in a society that can either favor or obstacle socioeconomic mobility (Albury, 2020). As Ngizwenayo (2017) points out, through language ideologies, it is possible to understand why people consider a certain language as 'important' and why they would be motivated to learn it. Following her study on students' perception of language use in Aruba, results showed that Dutch is perceived as 'necessary' when looking for higher position jobs, and it is associated with higher power and authority. Mastering the Dutch language also provides linguistic capital when planning to move to the Netherlands to pursue higher education. Angela (2023) highlights how nearly half of the young adults on the island choose to study abroad in the Netherlands between the ages of 17 to 25, which makes speaking Dutch at a professional level particularly important to some individuals (Geerman, 2020).

In Aruba, English also plays a crucial role in providing educational and professional opportunities, which can also be explained by the presence of the Lago Oil and Transport Company from 1924. Since the refineries were mostly managed by people from the United States, the main language used in this industry was English, and a lot of people from the English-speaking Caribbean also migrated to Aruba to work, notably to Saint Nicolas, leading 8% of the current population being native (Caribbean) English-speakers (Mijts, 2021). Since the refinery closed in 1985, the main source of economy has been tourism, with mostly monolingual English-speaking tourists from the U.S. and Canada choosing Aruba as their holiday destination. As such, English has assumed the role of 'lingua franca' which

allows interaction between locals and tourists on the island (Lo-Fo-Sang, 2022). In addition to this, the Aruban community is in contact with the English language through television and social media, where the language is the most dominant, together with Spanish. Spanish is relatively common in Aruban households, considering the high influx of migrants from Latin America in the last 50 years, notably Colombia and Venezuela (CBS, 2023).

Multilingualism can also be seen as an advantage for professional opportunities. This current, increasingly globalized world tends to reward the cognitive, intercultural, and social benefits of multilingualism (Barakos et al., 2019). Multilingualism is valued as a resource, useful for business, and linked with 'innovation'. However, only a few studies have been dedicated to the ideologies behind this belief. Barakos et al. (2019) describe 'elite multilingualism' as a phenomenon that brings capital, prestige, and access using only certain linguistic resources for certain groups of individuals. In that sense, multilingualism is not neutral, as languages assume a 'hierarchical' order in society which still only benefits the dominant groups.

3.4. Intergenerational Changes in Language Ideologies

The concept of intergenerational change refers to the transmission of values, practices, and beliefs between generations. Language, along with its underlying ideologies, can be transmitted across generations as a form of capital, shaping and being shaped by its historical, political, and socioeconomic contexts (Angela, 2023). Because these dynamics influence not only how language is used, but also how it is valued and taught over time, I chose to include the intergenerational dimension in this research. As Suslak (2009) notes, linguistic change is always in motion, making it essential to consider how different generations experience and contribute to that process. At the same time, it is important to mention that language change is a continuous process, and that the way we categorize and define generations is a social construct.

Exploring intergenerational realities is particularly important in multilingual realities like Aruba, where individuals' experiences, beliefs, and attitudes toward languages are influenced by several factors. In monolingual realities, the children's access to language is highly influenced by the previous generations (e.g. parents and grandparents), often speaking varieties of the same languages in both the familiar and formal domains (Ouen, 2003). In multilingual contexts, children from different linguistic groups can have varying degrees of access to the languages in the different domains of life, and parents can only partially 'control' the language use and beliefs of their children (Ouen, 2003). In the latter context, intergenerational changes are even more complex to observe, as external factors such as dominant ideologies expressed in language policies can have an important impact on individuals' views of a certain language.

In the case of Aruba, language policies have historically reflected the colonial relationships within the Kingdom of the Netherlands, as these policies promote monolingual ideologies through Dutch as the language of education. Nevertheless, the effort that is being made to emphasize the importance of the majority language, Papiamento, must be acknowledged. In 2003, Papiamento gained its status as the official language of Aruba next to Dutch, and researchers, together with policymakers, are actively working towards more inclusive, multilingual policies (Mijts, 2021). A concrete example is the introduction of multilingual primary education in 2012, part of the project named Proyecto Scol Multilingual (Mijts, 2021). Consequently, the changes in language policies and practices in Aruba must be accounted for when exploring language ideologies, as this would help understand whether the more multilingual ideologies are top-down initiatives, proposed in policies by institutions, or bottom-up, with the community advocating for more multilingual policies

3.5. Between Language Ideologies and Policies

In Aruba, language policies often favor using Dutch by treating it as obvious and self-evident due to the historical and political colonial ties to the Netherlands (Mijts, 2021). On the other hand, the efforts for the introduction of policies designed to build inclusivity in the use of Papiamento or English must constantly be demonstrated and defended (Mijts, 2021). Language policies are inevitably ideological and political, as they involve public decisions about language development, use, and status (Canese, 2018).

While language ideologies inevitably inform policy, their relationship is not linear: different language policies may share a common underlying ideology, and similar language policies may derive from opposite ideological orientations (Canese, 2018). Furthermore, ideologies in a post-colonial context do not only flow in one direction: ideologies are shaped by people on both sides of the colonial divide (Canese, 2018). Moreover, top-down forces related to language ideologies are often expressed through language policies, assessment tests, and the design of the language of education (Farr et al., 2011). Still, bottom-up forces in society have their language ideologies, and so they could choose to conform, ignore, or resist top-down policies, (Farr et al., 2011). For instance, while the exclusive use of Dutch in formal contexts imposes monolingual ideologies, the community could still ignore or resist by adopting multilingual ideologies in and outside the classroom.

4. Methodology

4.1. Participants

Participants have been initially recruited through convenience sampling based on social interactions of the researcher with the community, and through snowball sampling once more participants were found. The choice of including participants who identify as Aruban rather than just those who were born or are Aruban by heritage was purposefully made to gain a more nuanced view of the different realities in the island. I kindly invited participants to join this project both through oral interactions and via social media.

The sample consists of 15 individuals who identify as Arubans. The ages ranged between 17 and 70, and they were grouped into two generations: Generation Z included the 11 participants born between 1996 and 2012, while Generation X included the 5 participants born between 1955 and 1982.

4.2. Data Collection

The research design of this project consists of semi-structured interviews, both via focus groups (4 in total) and individual interviews (3 in total). Focus groups last between 1 and 1.5 hours, while individual interviews are approximately 30 minutes. While the initial goal was to merely conduct focus groups, individual interviews were purposefully allowed to accommodate respondents who felt more comfortable sharing their experiences alone, as well as for time constrictions. In the focus groups, participants are already familiar with each other, either being members of the same family or being a group of friends.

4.2.1. Measurement Instrument

An open-ended questionnaire consisting of 20 questions was created for the interviews to measure language ideologies concerning educational and professional opportunities in Aruba. The quantitative survey by Kiramba et al. (2023) served as an inspiration to formulate questions related to language (in)tolerance, language support, and language and politics.

Additionally, questions about the demographic characteristics (age, country and year of birth, occupation) and language background of participants were included. To understand the influence of Dutch as the main language of

education in shaping people's ideologies, I ask about their experiences, and feelings towards the current state of the language of education. Their idea concerning speaking 'correct Dutch' in and outside school is also discussed, followed by a question related to confidence in the different languages. Participants are also asked to reflect on the importance of language for access to educational and professional opportunities in Aruba and abroad. A question concerning language(s) and their importance for Aruban identity is also included. While the order of these questions slightly varied according to the direction of the conversation, all of them were asked during every interview, and the interview always ended with the final question: 'What do you hope, in terms of language, for future generations?'.

4.2.2. Procedure

Interviews were conducted at a date and location that was convenient and comfortable to all participants, such as the University of Aruba patio or a quiet café, and they were audio-recorded with consent from participants. Their consent was requested orally at the beginning of the interview, following a short explanation of the content and the scope of the session.

Considering my linguistic background (Italian, French, English), most interviews were conducted in English. However, participants were welcome to answer in the language variety they felt more comfortable with. In one focus group, one of the participants only spoke Spanish, and communication was made possible thanks to the participation of the student (and friend) Gabriela Lopez Valle, a Spanish speaker. Transcription of the recordings was done through the website TurboScribe (2023). Interviews were transcribed (and sometimes translated to English) with the collaboration of the Academic Foundation Year student Richelisse van den Berg, who helped in the understanding of knowledge in Papiamento, Dutch, and Spanish as well as the contextualization of the responses concerning Aruba. Data was made anonymous during the transcription phase.

4.2.3. Data Analysis

Relevant data was identified, analyzed, and reported through a thematic analysis approach, which involved searching across the data set to find repeated patterns of meaning. The analysis was performed at the latent level, which means that broader, underlying ideologies were interpreted from what was articulated in the data (Braun et al., 2006). This process was done via the NVivo Qualitative Software (Lumivero, 2024) following the six-step method outlined by Braun et al. (2006). While the frequency of themes across participants was considered, it was not fundamental in determining its relevance in the research.

5. Preliminary Results

Based on the interviews done so far, I identified the themes that stood out the most in the context of this project. These findings are preliminary and are still in the early stages; more data still needs to be collected to expand the investigation. However, they are already helpful in providing a picture of the Aruban community's language ideologies. As mentioned above, ideologies are underlying patterns of meaning, and it is very unlikely to find them explicitly in individuals' discourses. That means that a deeper analysis is needed to draw more accurate conclusions from their attitudes. As for now, I present my preliminary results, where I describe the main content of the interviews according to the themes. The quotes by the participants are signaled by single quotation marks (') and text in italics.

5.1. Language Ideologies and Dutch as the Language of Education

When I asked participants how they felt about Dutch being the main language of education on Aruba, the answers

were rich and diverse. As a non-Aruban researcher, most participants started by presenting me the *'reasons behind it (Dutch)'*, being the colonial ties within the Kingdom of the Netherlands. Their opinion about it was useful for understanding people's perspective on the (mostly) monolingual education in Aruba.

Most of them also affirmed that Aruban education is dependent on the (European) Dutch education and, quoting a participant, *'you are going to have to live in Dutch, there is no passing that. So, I would say, it is easier to begin from a young age.'* Rather than questioning whether Dutch should even be a language of education in Aruba, participants focused the conversation on when Dutch should be introduced to Aruban students during their academic journey.

A few people argued that, because secondary education would be Dutch anyway, it would be more convenient to start from a young age. Some participants did not agree with the recent policies that increased Papiamento's presence in kindergarten and primary school, and they sometimes described it as 'unfair' as children are exposed to Dutch too late. As a participant pointed out, it is a big dilemma whether it is more beneficial to *'understand your primary language so that you can understand better your secondary language, or if that means that you get it late, and the chances of development are already lower'*. Some participants even said they 'loved' Dutch as the language of education because they were 'good at it', while they also recognized that not every student had the same positive experience. By doing so, those participants seemed to acknowledge linguistic diversity in the community, showing a more inclusive ideology.

These initial findings partially resonate with the monolingual ideologies when thinking of the (sole) presence of Standard European languages in education as the norm (Blackledge, 2000). However, most participants also showed positive attitudes towards the (potential) presence of other languages in education, aligning with multilingual ideologies.

The teachers' linguistic background, particularly their proficiency in Papiamento, was a topic that spontaneously appeared during several of the interviews. The monolingual ideologies in the classroom were not intrinsically dependent on the language policy which promotes Dutch as the only language to be used, but rather on the teachers' competence and attitude towards it. This aligns with Farr et al. (2011), who highlighted the importance of the community in adopting (or not) the dominant ideologies imposed by institutions. Also, these results are consistent with Martinez et al. (2015) who previously highlighted the role of teachers in promoting ideologies in the classroom.

Comparing generations, the presence of Aruban teachers is more frequent for the younger generations compared to the older ones, where the presence of European Dutch teachers was more dominant. Older participants described their teachers as 'very very Dutch', or in other words, monolingual Dutch speakers from the European Netherlands. According to the younger generations, even Papiamento-speaking teachers mostly teach in Dutch, but their understanding of the majority language (Papiamento) was described as important for the students' experiences, where switching languages was more welcome. When struggling to find a word in Dutch, instead of being *'forced to figure it out'*, the use of Papiamento could help students and teachers to understand each other, saving time and discomfort.

Opinions towards speaking 'correct' Dutch at school were one of the questions of the interview. This implicitly referred to the concepts of 'standardization' and 'linguistic purism' present in monolingual ideologies that see languages through a normative lens (Baioud et al., 2022). A few participants thought that, if you can't speak Dutch well, *'you basically fail'*. On the other hand, some said that having 'perfect' proficiency in Dutch was not that important during their education, until the last year of high school when they had to pass the final exams. An important aspect that was mentioned is the fact that exams come from the European Netherlands, which makes their language variety, context, and culture the standardized version to use across all the countries in the Kingdom of the Netherlands. As

Sollie (2015) previously described, the fact that assessments are based on standardized, monolingual European Dutch education plays an important role in students' feelings about their competence in Dutch. According to some participants, even if speaking 'perfect' Dutch was not fundamental during school in Aruba, if planning to move to the Netherlands after, speaking it well becomes important. A lot of participants said that most Arubans *'do not speak Dutch perfectly'*, and some participants also shared their difficulties in learning Dutch, as they evaluated their competence as *'bad'*, or *'cowboy Dutch'*. On the other hand, some also acknowledged the fact that *'Dutch people in the Netherlands also cannot speak Dutch perfectly'*. These findings are especially interesting when reflecting on the notion of 'correct' language itself and its normative nature.

5.2. Multilingual ideologies and multilingual education

A participant defined Dutch being the language education as a 'crime', referring to the difficulties that most (non-native Dutch speaking) students face when thrown into the monolingual education on Aruba. Participants were asked to express their opinions both on multilingual education proposed in current projects such as Scol Multilingual, and their ideal multilingual reality in education. This topic served to open the discussion on beliefs towards multilingual education.

Most participants agreed on the fact that Papiamento should be a language of education, with some also arguing it should be the main one. English and Spanish were also mentioned as languages that should be taught in school, considering their importance in Aruban society. Some participants had positive feelings when reflecting on the results of the Scol Multilingual, tellin how former students who attended it *'obtained the same, if not better, results compared to students who attended monolingual Dutch education'*. According to some, it is widely known that schooling in Dutch is not always 'better' for students.

Participants also expressed their opinions on whether the government should or should not invest more money in multilingual education. Most of them recognized the existing efforts to preserve Papiamento and implement it in Aruban education, such as in the Scol Multilingual. A participant also thought that, although the government is investing money in preserving Papiamento, for example through the creation of books in and about the language, there is still *a lack of interest in reading and writing in general,* or in buying books in Papiamento.

The importance of preserving Papiamento was mentioned by almost all participants, described by one as being *'the only thing we have from our culture that is untouched'*. Different ways to do it were discussed, for example, by collecting material in the national archives in Papiamento that is available and accessible to the community, or by creating a database of Papiamento that can be used for several domains, from education to health. A participant also mentioned how the present technological tools such as online translators often adopt the variety of Papiamentu from Curaçao, which comes at the expense of the Papiamento from Aruba. To contribute to the preservation of Papiamento, the expertise of the Papiamento-speaking community was considered fundamental, particularly the few people who specialized in Papiamento during higher education.

While conducting this research, I was curious to know what role languages have in shaping Aruban identity, even if I did not know yet how this would fit into my research goals. Thanks to the answers of participants, I realized that this was connected to the European-based monolingual assumption of 'one language, one people'. Some participants said that Papiamento is the language of the Aruban people. Some said that while the other languages on the island (Dutch, Spanish, English) are common and welcome, *'if you have some Papiamento, you will be considered Aruban'*. A few participants also mentioned how they appreciate the effort

of newcomers to the island to learn Papiamento, and how learning the minority language has gained more recognition in the last decades. Interestingly, some participants also found my question irrelevant, describing Aruba as a *very big melting pot, so you can't really have requirements for language (…) you can't tell them they are any lesser Aruban. As long as you feel Aruban, you are Aruban.* Another response particularly impressed me: *'it does not matter to me, and besides, who is Aruban? Everybody is important here. Not even the cacti, the rocks…everybody is an immigrant here. From ancestors to now. So, who is Aruban? That one that carries the flag, that's it'.*

5.3. Languages as resources in Aruba and abroad

During the interviews, I asked participants their opinions on how important the different main languages on the island (Dutch, English, Papiamento, and Spanish) are to access educational and professional opportunities in Aruba and abroad. By doing so, my goal was to understand whether participants see the different languages as resources, and to what extent.

The general opinion was that *'most people want to move to the Netherlands, and some of them are not coming back, some come back before the time (of end of their studies)'*. This aligns with previous findings describing the frequent migration path of Aruban students to the Netherlands (Geerman, 2020). Most participants considered it important to know the language of the country where they plan to move, and especially if they are planning to follow a program in Dutch, they need to *'level up'*. Participants also explained to me that several programs at the University of Aruba are taught in English, so Dutch is not essential to continue their education on the island. Besides the Netherlands, the United States and Canada were mentioned as the main 'dream' destinations to move to, so in that case, English is considered more important for professional opportunities. A few participants also mentioned that some students also move to Latin or Central America to continue their studies, notably in Colombia and Costa Rica, which makes the Spanish language also important.

Regarding professional opportunities in Aruba, the role of English in tourism was particularly dominant, following previous literature (Mijts, 2021). All participants mentioned the essential role of English on the *'tourist island'* of Aruba, and *'if you want to get a job in this sector, especially in higher positions, English is needed'*. Participants described English as the *'world language'* or *'default language'* used in Aruba, not only in the tourism sector but also to interact with the U.S. market in other types of businesses. In this sense, not being proficient in English can be a big barrier. The role of Papiamento in access to opportunities was rarely mentioned, and from the interviews, it seems speaking Papiamento is not a requirement to find an occupation, but more of a necessity if you plan to interact with the local community. However, participants also pointed out that speaking the language of the community can be fundamental in certain cases, and in some sectors, such as healthcare, speaking Papiamento can be crucial to help Papiamento-speaking patients understand and request the help they need.

Talking about multilingualism in general and whether it is 'a curse' or 'a blessing', participants expressed different opinions. In general, participants were aware that (foreign) people find it 'impressive' when Aruban people say they speak multiple languages, 'especially because they are quite different' from each other. On the other hand, most participants found multilingualism the norm rather than the exception resonates with the multilingual ideologies described in the literature above, seeing multilingualism as unmarked (Albury, 2020).
According to most, multilingualism can be a resource just like in other (Western) countries where multilingualism is more *'special'* and being able to *'toggle in between all these languages'* can be quite helpful for professional opportunities.

In terms of educational opportunities, a participant said that *'knowing more languages doesn't really open more doors for you',* considering that university programs in Aruba and the Netherlands are monolingual. One participant viewed multilingualism more as a *'necessity*', saying that languages are '*important because we depend on the outside. We need Colombia. We need Venezuela. We need the States. We need Europe. And here, hotels are mostly American and Canadian, and some people are from Europe*'.

When describing the multilingual realities of Aruba, most participants mentioned their capacity to *'adapt to people coming in*', often adapting their language according to the other speakers' preferred (dominant) language, but also just *'depending on the friend group*'. Most participants are proud of this aspect of the Aruban culture, saying that they *'get along somehow with everybody*'. When I asked about hopes for future generations, one participant said that *'we tend to speak the language of the other person. we have to stop that;* they said this in the context of a broader discussion on how, by adapting to others and their languages, the preservation and maintenance of Papiamento are threatened.

5.4. Intergenerational Changes in Language Ideologies

For each of the four main languages present on the island, I asked every participant whether they thought the language was more or less important than before. The importance of Papiamento in the Aruban community was not debated, while intergenerational changes were still noticed.
Most participants thought that Papiamento is generally considered more important than before, considering the implementation of Papiamento language in primary education. One participant also described the language situation in Aruba as a *'political issue*' telling how there is this general idea that Arubans *'have to be more patriotic and put our language everywhere*' which helped the community value Papiamento as important in the society. Some participants thought that *'people are using Papiamento less now than before',* and new generations tend to code-switch to other languages more. Related to this, there was a general idea that the older generation speaks more 'Papiamento Puro', being the language without 'mixing other' languages in the conversation. This assumption can be associated with monolingual ideologies and linguistic purism, while, as described above, it can also be an act of resistance to maintain the minority language against colonial oppression (Baioud et al., 2022).

Most participants considered the importance of Dutch as quite 'stable' compared to 20 years ago, being still quite dominant in the educational setting, and no extensive answer was given about it. A participant highlighted the limited importance of Dutch on a global scale, and according to them, *'Where do you go with Dutch? Dutch, you can only speak it in the Netherlands, and here in the islands. Where else?'*. For instance, it is possible that while the role of the Dutch within the Kingdom is still considered important, its relevance outside the Kingdom could have diminished.

Concerning English, all participants affirmed that it is more important than before, especially for the tourism sector. A participant considers English in Aruba as *'newer compared to the other three languages*', as it started spreading on the island only in the last century, with the oil refinery, before tourism started booming. Another participant said that English is not necessarily more important among locals, as *'to us here, it is not beneficial unless you work in tourism*'. English was also described as important, in general, as the language people use to switch when they do not understand each other.

The importance of Spanish, especially compared to English, was quite interesting to hear. Most participants say that, although its presence on the island is rarely questioned, it is less important than before. English replaced the role that Spanish was occupying as the main language used for

television and media. However, the geographical proximity to Latin America, together with the high presence of Spanish-speaking migrants on the island, still gives Spanish an important role in the Aruban community.

6. Limitations

This exploratory study presents some limitations, starting with the 'construct validity bias', referring to the difficulty in measuring the main construct, ideologies. Considering the abstract, nuanced, and sensitive nature of ideologies, it can be challenging to measure them accurately, as they might be expressed inconsistently or implicitly. Participants might also have been influenced by 'social desirability bias', shaping their responses based on what is perceived to be socially acceptable. The 'language bias' during data collection also must be mentioned. Participants might have expressed themselves differently in other languages than English, especially when discussing language hierarchies.
While my study aims to include the diverse perspectives of the Aruban community, the sample is partly biased. Participants were recruited based on ease of access (availability, social networks, locations), which may not reflect the diversity of the wider population. For instance, some parts of the Aruban population may be underrepresented, such as people from different socio-economic statuses, ethnicities and age. Although the study aims to be intergenerational to cover a wider range of people's perspectives, the younger generation is currently overrepresented compared to the older generations.
Lastly, the findings are still preliminary, which means that the observed trends might shift once more data is collected and analyzed more in-depth, and conclusions drawn at this stage of the project may need to be revisited or refined.

7. Conclusion

This study investigates monolingual ideologies in the multilingual realities of Aruba. Through a Community-Engaged Research approach, I conduct individual and focus-group interviews with the Aruban community to explore the presence of language ideologies concerning educational and professional opportunities.

Preliminary results show the dominance of monolingual ideologies, when it comes to Dutch as the language of education, often being considered as 'normal' considering the colonial ties with the Kingdom of the Netherlands. On the other hand, most participants recognize the struggle that some students face when encountering Dutch monolingual education and their insecurities about their level of proficiency. The role of teachers' linguistic background and language use is often mentioned as crucial to shaping students' language ideologies.

Multilingual ideologies seem to be widely shared by most of the participants, who support the idea of multilingual education in Aruba. Preserving Papiamento as an important language for the community was an idea shared by all participants, who valued it as part of Aruban cultural heritage. Multilingualism also seems to be inherently part of Aruban identity, where being multilingual is more the norm than the exception. Concerning language(s) as capital, Dutch seems to be an important resource when planning to move to the Netherlands. English is believed to be important, especially when working in the tourism sector in Aruba, but also in general as a 'lingua franca' in the world. Papiamento did not seem to have a fundamental role in accessing professional opportunities, while it is considered important to interact with the local community in Aruba. Overall, multilingualism was considered a valuable resource both for professional opportunities and as a tool to adapt to speakers from different languages during social interactions.

Additionally, including participants from different ages helps reflecting on possible intergenerational changes in the community's language ideologies. Language policies

are perceived to be increasingly more inclusive, working on the implementation of Papiamento in education. On the other hand, some participants perceived that Papiamento is spoken less 'purely' than before and advocated for its maintenance. According to the data, the importance of Dutch across generations remains stable, while English has become more important, partially replacing the role of Spanish as the main language of media.

Although the present findings are still preliminary, they provide valuable insight into language ideologies in Aruba and how they influence language policies and access to resources for the Aruban community. This study also contributes to developing knowledge of the sociolinguistic dynamics in the Caribbean, highlighting the importance of inclusive multilingual policies, and of preserving the minority language in the island. This study will hopefully inform future policy reforms and help foster a more equitable and linguistically diverse society in Aruba.

References

- Albury, N. (2020). Language attitudes and ideologies on linguistic diversity. In A. C. Schalley & S. A. Eisenchlas (Eds.), Handbook of Home Language Maintenance and Development (pp. 357–376). De Gruyter. https://doi.org/10.1515/9781501510175-018
- Angela, S. (2023). A Bourdieusian Perspective on Aruban Student Mobility. Uppsala Universitet.
- Anzaldua, G. (1987) Borderlands/La Frontera: The New Mestiza. Aunt Lute Books, San Francisco.
- Baioud, G., & Khuanuud, C. (2022). Linguistic purism as resistance to colonization. Journal of Sociolinguistics, 26(3), 315–334. https://doi.org/10.1111/josl.12548
- Barakos, E., & Selleck, C. (2019). Elite multilingualism: Discourses, practices, and debates. Journal of Multilingual and Multicultural Development, 40(5), 361–374. https://doi.org/10.1080/01434632.2018.1543691
- Bastardas-Boada, A. (2019). Biological and linguistic diversity: University of Barcelona.
- Blackledge, A. (2000). Monolingual ideologies in multilingual states: Language, hegemony and social justice in Western liberal democracies. Estudios de Sociolinguistica, 1(2), 25–45.
- Bouchard, M.-E. (2024). Language ideologies and the use of French in an English-dominant context of Canada: New insights into linguistic insecurity. Multilingua, 43(3), 427–453. https://doi.org/10.1515/multi-2023-0109
- Bourdieu, P. (1991). Language and symbolic power. Cambridge: Polity Press.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa
- Canese, V. (2018). Language Ideology as a Conceptual Framework to analyze issues related to Language Policy and Language Education. Revista Cientifica de La Faculdad de Filosofia.

- Centraal Bureau voor de Statistiek Aruba & Dienst Burgerlijke Stand en Bevolkingsregister Aruba. (2023). Immigration to Aruba in the Last 50 Years. Aruba.
- Degraff, M. (2009). Chapter 7. Creole Exceptionalism and the (Mis)Education of the Creole Speaker. In J. A. Kleifgen & G. C. Bond (Eds.), The Languages of Africa and the Diaspora (pp. 124–144). Multilingual Matters. https://doi.org/10.21832/9781847691354-011
- DeGraff, M. (2009). Language Acquisition in Creolization and, Thus, Language Change: Some Cartesian- Uniformitarian Boundary Conditions. Language and Linguistics Compass, 3(4), 888–971. https://doi.org/10.1111/j.1749-818X.2009.00135.x
- Dijkhoff, M., & Pereira, J. (2010). Language and education in Aruba, Bonaire and Curaçao. In B. Migge, I. Léglise, & A. Bartens (Eds.), Creole Language Library (Vol. 36, pp. 237–272). John Benjamins Publishing Company. https://doi.org/10.1075/cll.36.10dij
- Faraclas, N., Kester, E.-P., & Mijts, E. (2019). Community Based Research in Language Policy and Planning: The Language of Instruction in Education in Sint Eustatius (Vol. 20). Springer International Publishing. https://doi.org/10.1007/978-3-030-23223-8
- Farr, M., & Song, J. (2011). Language Ideologies and Policies: Multilingualism and Education. Language and Linguistics Compass, 5(9), 650–665. https://doi.org/10.1111/j.1749-818X.2011.00298.x
- Geerman, E. (2020). Structures of multilingual code-switching among Arubans living in the Netherlands. Utrecht University.
- Han, H. (2011). Social inclusion through multilingual ideologies, policies and practices: A case study of a minority church. International Journal of Bilingual Education and Bilingualism, 14(4), 383–398. https://doi.org/10.1080/13670050.2011.573063
- Kiramba, L. K., Deng, Q., Gu, X., Yunes-Koch, A., & Viesca, K. (2023). Community language ideologies: Implications for language policy and practice. Linguistics and Education, 78, 101251. https://doi.org/10.1016/j.linged.2023.101251
- Lo-Fo-Sang, K. (2022). The Current Context of the Language of Instruction in Aruban Education: Towards a more inclusive Multilingual education. Utrecht University.
- Lumivero (2024) NVivo (Version 15) www.lumivero.com
- Martínez, R. A., Hikida, M., & Durán, L. (2015). Unpacking Ideologies of Linguistic Purism: How Dual Language Teachers Make Sense of Everyday Translanguaging. International Multilingual Research Journal, 9(1), 26–42. https://doi.org/10.1080/19313152.2014.977712
- Mijts, E. (2021). The situated construction of language ideologies in Aruba: A study among participants in the language planning and policy process. University of Aruba.
- Ngizwenayo, Z. (2017). Adolescent perceptions on language and professional communication. In UAUCU. Student Research Exchange. Collected Papers 2017.
- Skutnabb-Kangas, T. (2003). Linguistic diversity and biodiversity: The threat from killer languages. CROSS CULTURES, 65, 31-52
- Sollie, F. (2015). Language and education in a multilingual society: Text comprehension and language attitudes among Aruban high school students. In UAUCU. Undergraduate Student Research Exchange. Collected Papers 2015.
- Suslak, D. F. (2009). The sociolinguistic problem of generations. Language & Communication, 29(3), 199–209. https://doi.org/10.1016/j.langcom.2009.02.003
- TurboScribe. (2023). Turboscribe.ai. https://turboscribe.ai/?ref=gad-self-2023-11-28&gad_source=1&gclid=CjwKCAjwy8i0BhAkEiwAdFaeGKLiMxJHdB561DaPmqnFoujLAt03ilHrC-O4KcYYptlkQe4Ox4u-KBoC9_IQAvD_BwE
- Verschueren, J. (2012). Ideology in Language Use: Pragmatic Guidelines for Empirical Research (1st ed.). Cambridge University Press. https://doi.org/10.1017/

CBO9781139026277

- Wodak, R. (2007). Language and Ideology—Language in Ideology. Journal of Language and Politics, 6(1), 1–5. https://doi.org/10.1075/jlp.6.1.01wod
- Zúñiga, D. (2025). How many worlds are there? One, but also many: Decolonial theory, comparison, 'reality.' European Journal of Political Theory, 24(2), 264–287. https://doi.org/10.1177/14748851231214252

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10 OUT OF 4160.

"Take a sheet of paper. Divide it into 80 blocks and each block into 52 other blocks. Now color 10 of these 4160 blocks. That doesn't look like much, does it?". I owe a lot to the person that told me this as it helped me find it in me to leave my home for 10 weeks and embark on an experience that changed my life. I was scared, but it turned out to be the best choice I could make: 10 weeks might look like nothing relative to a whole life, but they could have an impact you could not imagine before leaving for the place that will become home.

The Aruba field research program had been in the back of my mind since I applied to UCU, although I never really considered it as a possibility until the end of my second year. Too many curriculum planning issues and doubts about the future to consider moving to the other side of the world for three months. However, when I received the email that applications were open for the 2025 edition of the program, I realized the idea had never really left the back of my mind: do I want to spend 10 weeks of my last semester at UCU on an island with 11 strangers to work on my own thesis project from start to finish? I figured why not.

Now, almost at the end of this journey, I can say with certainty that this time in Aruba has managed to be, like a lot of things in life, so complicated yet so great. It was not easy to find summer clothes during winter, but it was great to see the ocean while driving to meetings. It was not easy to work up the courage to knock on people's doors asking for help, but I am very proud of myself for never hiding from that and always looking for alternatives to what did not turn out as I expected. It was not always easy to make things work in a group with such different people, but I can say these 11 once-strangers all left a mark in my memories as I hope I left in theirs: thank you for everything, from the late night swims and the birthday cake to the support and laughs about being ghosted by stakeholders.

So many other people made my experience in Aruba what it has been. First, I am grateful to our Aruban classmates, who welcomed and led us into life on the island. I also want to thank Jocelyn and Frank for supporting my ideas since our first meeting, and Eric, for showing me that it's okay and actually great to be interested in so many seemingly unrelated things, from language to nature. I also greatly appreciate everyone that got involved in this project: Sigmund, Nancy, and Janis from the Bureau Centro Multidisciplinario, the principals and teachers at the schools I visited, and all the parents and children who ultimately made this possible.

People that shared my experience from afar also shaped it significantly. I want to thank my family for always inspiring me and believing in me even when they had no idea what I was doing. I am also thankful to my housemates for convincing me to apply for this program and to my friends Ola and Yasin for always being there for me.

Finally, thank you to my roommate, Sofia, for simply being the person I could go back to every evening.

I will forever keep Aruba and its people in my heart (at least until I come back again), just as I still keep the sheet of paper with the 4160 blocks in the back of my bookshelves and my mind.

DEVELOPMENTAL LANGUAGE DISORDER IN THE ARUBAN MULTILINGUAL CONTEXT:

Investigating the Cross-Linguistic Non-Word Repetition task to standardize diagnosis and improve support

Sofia Amigoni

1. Introduction

Language acquisition is one of the most important, yet seemingly effortless milestones in childhood, forming the foundation for social interaction, cognitive development, and later academic success (Gillam et al., 2021). However, this process is not so easy for children with Developmental Language Disorder (DLD), a lifelong condition affecting 3-10% of school-aged children in Aruba and worldwide. DLD is three times more common in males than females and it leads to difficulties in learning, understanding, and using language, in the absence of a clear external cause, such as cognitive deficits or hearing loss (Gillam et al., 2021; UCL, 2024). Indeed, it is not caused by other biomedical impairments, as well as emotional or environmental deficits (Baird, 2008; Gillam et al., 2021). Over the course of their lifespan, individuals suffering from DLD face significantly more challenges and drawbacks in education, employment, and mental health than those without language impairments (LIs), that is to say those with typical language development (TD) (Nudel et al., 2023). This is reflected in lower academic achievement and income and higher incidence of depression (Nudel et al., 2023). To date, research has investigated DLD in monolingual and bilingual populations and contexts, focusing on individuals exposed to one or two different languages and proficient in one or both. However, little is known about how it affects children growing up learning several languages in a multilingual environment

1.1. Aruban linguistic environment

In many parts of the world, especially amongst migrant communities and in former colonies of the global south, multilingualism is the rule rather than the exception (Faraclas et al., 2019; Wouda et al., 2024). Despite this linguistic diversity, the education systems are often structured in ways that assume that children are monolingual in the language of education (Faraclas et al., 2019; Mijts et al., 2018). It has been estimated that up to half of the world's population is taught in a weak second language or a completely foreign language (Baker & Jones, 1998; Campbell et al., 1997; Ortiz, 2021; Paradis, 2011). The mismatch between the pupil's mother tongue and the language of instruction is clearly seen in Aruba, where the Dutch education system is implemented despite the island's multilingual population.

As shown in Figure 1, most of the population born in Aruba considers Papiamento as their home language (68%), followed by Spanish (14%), English (8%), Dutch (6%), Chinese (3%), and others (1%) (CBS, 2020). Hence, most, if not all, local children are exposed to at least three languages: Papiamento, since it is the language of inheritance of most Aruban families and the one mainly used in day-to-day interactions between peers, Dutch, due to education, and English, due to social media and tourism (Lo-Fo-Sang, 2022; Mijts et al., 2018; Sollie, 2015). In addition, Spanish

is relatively common in households due to migrations from neighboring Spanish-speaking countries, namely Colombia, Venezuela, and Dominican Republic (CBS & DBSB, 2023). Hence, the majority of Aruban children can be defined as multilingual, based on the definition by the International Expert Panel on Multilingual Children's Speech: this states that multilingual people, including children acquiring more than one language, can understand and/or produce two or more languages in oral, manual, or written form with at least a basic level of functional proficiency or use, regardless of the age at which the languages were learned (IEPMCS, 2012).

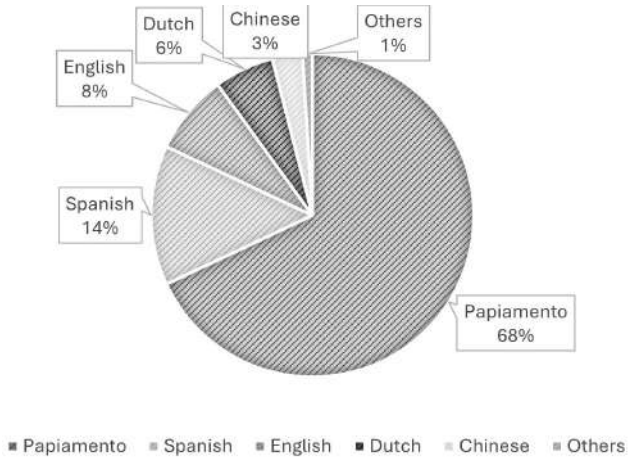

Figure 1. Most common languages spoken in Aruban households by percentage.

In public schools on the island, the language of instruction is Papiamento during kleuteronderwijs (pre-school education, from age 4 to age 6), but switches to Dutch during basisonderwijs (elementary education, from age 6 to age 12) onwards. Papiamento instruction was introduced in grade 1, attended by pupils aged five to six, only in 2024 (Felix, 2024). The policy shift came in response to a UNESCO statement that the Dutch educational model did not fit the local needs (Felix, 2023). Indeed, Dutch may not be the language in which Aruban children perform best or are most comfortable, as the majority of them do not encounter written or spoken Dutch outside of the classroom and, therefore, not before they reach approximately age 5 (Mijts et al., 2018; Sollie, 2015). Children of Dutch or Surinamese origin are the only ones who start school with prior knowledge of Dutch (Lo-Fo-Sang, 2022). Other children must quickly get used to the set of sounds in the language, known as phonetic inventory, as well as its vocabulary, syntax, or word order, and syllabic structure, referring to the patterns in which sounds are organized into syllables. These might greatly differ from those of the children's home language. For instance, Spanish is a Romance language, while Dutch and English come from the Germanic language family. On the other hand, Papiamento is a creole language, with most of its vocabulary derived from Spanish and Portuguese. However, its syntax is more similar to that of English (Chiat, 2015). These differences constitute a notorious barrier for many Aruban children, and even more so for those affected by an LI. Indeed, previous research suggest that learning how to express themselves and demonstrate their knowledge in a foreign language, such is the newly encountered Dutch language for Aruban pupils, comes to children with DLD at an even bigger cost than to those not affected by language impairments (Tribushinina et al., 2020).

1.2. Diagnosing DLD in Aruba

Due to the lack of literature specific to Aruba, information about the diagnostic methods currently in place was gathered through interviews. These were conducted with youth psychologists and speech-language pathologists (SLPs) employed in private practices as well as at the Bureau Multidisciplinair Centrum (MdC), the public institution providing free therapy in schools.

Taking into consideration the island's complicated linguistic panorama, the diagnosis of LIs such as DLD by Aruban

SLPs is currently mainly based on observations. By talking to the child, playing games, and observing spontaneous speech, the specialist assesses whether there are indications of a delay in the development of any area of language, such as vocabulary, sentence formation, and word-finding. However, these observations do not suffice to get extra support from the school, requiring the use of formal assessment methods. In this case, the most common tools are the translations of Dutch assessment tests, originally developed for monolingual Dutch-speaking children. Such tests are the Schlichting Taaltests, which are a collection of tasks assessing the language comprehension and production abilities of children aged 3 to 7 (Schlichting, 2012). These norm-referenced tests are used to assess a child's language and make comparisons with TD children of the same age to indicate how different their development is from average (Baker & Jones, 1998). While these standardized tests might seem like the best option, they are usually based on scores from monolingual native language children. This makes the use of these tests challenging in contexts like Aruba, where each child comes from a different background and is differently exposed to different languages. Hence, the language assessment and therapy must adapt to each child's unique background (Campbell et al., 1997).

1.3. DLD and multilingualism

Data from multilingual populations is lacking, meaning there is no standardized norm data to compare a multilingual child's linguistic development with. This is necessary since the problems encountered in language acquisition by monolingual children with DLD partially overlap with those met by TD multilingual children (Boerma et al., 2015), who are simultaneously exposed to different phonetic inventories, vocabularies, and grammar rules. In addition, a child affected by DLD may have difficulties in one language domain, such as vocabulary, sentence structure, or word formation, in one language, while they perform well in the same language domain in another language. (Baker & Jones, 1998). Indeed, when the same test is given to children from different ethnic, cultural, or economic backgrounds, there is the risk of confusing language differences with language disorders (Campbell et al., 1997). Language differences are attributable to different experiences and amount of exposure to different languages, while language disorders reflect deficits in the processing of language on a neurological level (Campbell et al., 1997).

Ideally, multilingual children with LIs are assessed in all the languages they are exposed to and compared to TD children of the same age who speak the same combination of languages. However, this is usually not possible in environments characterized by the presence and common use of several languages, where the linguistic background of each child is unique. Indeed, norm data is available for monolingual contexts and for the original assessments, not for the translated Aruban versions, which makes it complicated to determine whether a child's linguistic abilities are below average. In addition, multilinguals use their languages in different contexts, and they may have different linguistic competence in varying topics: comparison on monolingual norms assumes equal proficiency in all languages in all contexts, which is rarely the case for multilinguals (Baker & Jones, 1998).

This leads to more complicated diagnosis, possible misdiagnosis, and inadequate care. Children may receive a DLD diagnosis when their language difficulties derive from limited exposure to the specific language or domain being assessed, rather than an underlying disorder. In the same way, an LI might be overlooked, and the child might not get the support and therapy needed. Therefore, to diagnose DLD in a multilingual child, the regular norms for monolingual children cannot be employed (Boerma & Blom, 2017).

1.4. Cross-Linguistic Non-Word Repetition test

To mitigate the risk of misdiagnosis and distinguish between language problems caused by limited knowledge

of the target language and by real neurological impairment, the Language Impairment Testing in MUltilingual Settings (LITMUS) battery of tests was developed (Armon-Lotem & Grohmann, 2021). This includes cross-linguistically and cross-culturally applicable tools to assess different language areas: narrative abilities, via the Multilingual Assessment Instrument for Narratives (MAIN); lexical processing, via the Cross-Linguistic Lexical Tasks (CLT); phonological processing and memory, via the Cross-Linguistic Non-Word Repetition task (CL-NWR); syntax, morphology, and semantics via the Sentence Repetition task (SRep) (Hamdani et al., 2024). These tasks are designed to be minimally affected by knowledge of a specific language, but rather test general linguistic knowledge and skills acquired in any language. By tapping into cognitive functions that are critical for language acquisition, such as memory, attention, and phonological processing, they have been shown to be more accurate in distinguishing DLD from lack of language exposure than language-specific tools (Boerma et al., 2015; Boerma & Blom, 2017; Chiat & Polišenská, 2016; Schwob & Skoruppa, 2022). Indeed, the CL-NWR task does not distinguish between monolinguals and bilinguals according to most literature, which is encouraging for multilingual assessment (Boerma et al., 2015; Chiat & Polišenská, 2016; Schwob et al., 2021; Schwob & Skoruppa, 2022).

One of the most widely researched tests from the LITMUS battery is the CL-NWR, which has so far been suggested as accurate and reliable in identifying DLD in bilingual children: differences in language experience seem to have less effect on nonword repetition tests than on tests of vocabulary or grammar (Chiat, 2015). During these tasks, children are instructed to repeat word-like items that they have not heard before but are phonologically acceptable in the languages they have been exposed to. These target items are made-up sequences of phonemes, or sounds, thus they are not part of the participant's learnt vocabulary. However, they are constructed to sound like they could be real words in the languages involved in the study by following the rules shared by several of the world's languages, such as the simple syllabic structure of a consonant followed by a vowel. Therefore, children cannot benefit from the knowledge of, nor are they disadvantaged by limited exposure to, a specific language.

Repeating a nonword from the CL-NWR draws on children's general language knowledge, their ability to recognize speech sounds, and verbal short-term memory (vSTM) (Casalini et al., 2007; Chiat, 2015; Collée, 2018). vSTM is the ability to briefly hold and repeat spoken information, and difficulties in this area have been identified as a sign of DLD (Casalini et al., 2007; Collée, 2018; Meir, 2021; Vance, 2008). Children must recognize the phonemes in each item, briefly store them in memory, and report them in the correct sequence (Casalini et al., 2007; Chiat & Polišenská, 2016).

The 16 nonwords involved are equally divided between the lengths of two, three, four, and five syllables. To be maximally compatible with the world's diverse phonologies, the items present a limited range of vowel (/a, i, u/) and consonant (/p, b, t, d, k, g, s, z, l, m, n/) sounds, which are among the most common phonemes in world's languages (Chiat et al 2020). The test offers a set of alternatives for each item, since any specific sequence of phonemes could be an existing word in a particular language or a specific sound might not be part of its phonetic inventory (Faraclas et al., 2019; Mijts et al., 2018). In addition, the items are recorded in language neutral prosody, meaning with rhythm, tone, and pitch not specific to any one language (Chiat et al 2020).
Although not previously emphasized in studies on nonword repetition factors such as the practice effect, lexicalization bias, and systematic substitutions are commonly observed in language processing studies and could influence performance in the CL-NWR test. In particular, repetition of the same task can lead to improvements in performance, a phenomenon known as practice effect (Archibald & Gathercole, 2006). Lexicalization bias refers to subjects' tendency to process more easily items that resemble real

words in their languages or mispronouncing items in a way that is similar to real known words (Collée, 2018). Lastly, systematic substitutions are consistent and predictable replacements of one sound with another one in child's speech which reflect articulation abilities rather than underlying cognitive deficits (Boerma et al., 2015).

1.5. Parents of Bilingual Children Questionnaire

To better differentiate between DLD and limited language exposure in a bilingual child, parental questionnaires are increasingly used to collect information about the child's early and current use of and exposure to their languages (Tuller, 2015). Indeed, late emergence of language, such as delayed first words and smaller vocabulary size than expected, are possible indicators of DLD as included in the Diagnostic and Statistical Manual of Mental Disorders-5th edition (American Psychiatric Association, 2022). However, these can also be natural steps in the simultaneous acquisition of several languages by a multilingual child (Baker & Jones, 1998; Campbell et al., 1997; Öberg & Bohnacker, 2024; Ortiz, 2021; Paradis, 2011). In the same way, current language skills could indicate risk of DLD. For instance, parental reports can be employed to evaluate whether the child pronounces words well, is easily understood by other people, and often uses the wrong words or distorts words. Also, any family history of language impairments is a risk factor for the development of language delays or DLD which should be taken into account by speech-language pathologists (SLPs). Previous studies have also suggested that input quality and quantity could constitute external factors in a child's multilingual acquisition, such as length and frequency of exposure to a language, the contexts and activities in which a language is used, and parental socio-economic status (Paradis, 2011).

Therefore, the Parents of Bilingual Children Questionnaire (PaBiQ) was developed as part of the LITMUS test battery to gather information regarding seven themes:

- general information about the child;
- early child development (before the age of 4);
- current skills;
- languages used at home at the moment;
- further language use;
- information about the parents;
- language difficulties in the family.

This questionnaire has been shown to be particularly effective in combination with other assessment tools, such as the CL-NWR task, providing a more comprehensive picture of the child's language development (Boerma et al., 2015; Boerma & Blom, 2017; Tuller, 2015).

1.6. Current study

The diagnostic reliability of the LITMUS tasks for future clinical applications is currently being studied almost exclusively within monolingual and bilingual populations and they are not norm-referenced yet (Öberg & Bohnacker, 2024). Evidence for impaired NWR performance amongst bilinguals has been reported, although it is not as clear-cut as for monolinguals (Ortiz, 2021; Schwob et al., 2021; Schwob & Skoruppa, 2022). Thus, this project aims to contribute to the assessment of this test battery in multilingual contexts by evaluating the accuracy of the CL-NWR task in identifying DLD in multilingual children in Aruba, as well as by making comparisons with the assessment methods currently in place. The research questions which will be addressed are the following:

- RQ1: How do 5-7-year-old multilinguals from Aruba with a diagnosis of DLD perform on the LITMUS CL-NWR test and how is this performance affected by age and item length?
- RQ2: How do typically developing 5-7-year-old multilinguals from Aruba perform on the LITMUS CL-NWR test and how is this performance affected by age and item length?

- RQ3: How do these findings compare to previous studies that have used the CL-NWR test with bilingual populations?
- RQ4: Do these findings allow for any conclusions to be drawn about the clinical utility of the LITMUS CL-NWR test when assessing the language skills of multilingual children with suspected DLD?

This paper is a preliminary report presenting the findings related to RQs 1,3, and 4: data answering RQ 2 will be collected and analyzed for the final version of this paper.

Ultimately, this research aims to simplify diagnosis, improve diagnostic accuracy and support strategies for multilingual children with DLD. Findings could contribute towards the global goals of quality education and reducing inequalities, benefiting culturally and linguistically diverse populations worldwide.

2. Methodology

The methodology employed draws on previously mentioned studies and is optimized for the specific context and languages of Aruba (Boerma et al., 2015; Boerma & Blom, 2017; Chiat, 2015; Chiat & Polišenská, 2016; Meir, 2021; Ortiz, 2021; Schwob et al., 2021; Schwob & Skoruppa, 2022; Tuller, 2015).It adheres to the ethical guidelines for student research provided by Utrecht University. Parental informed consent was secured for participants. The information letter, informed consent form, and PaBiQ questionnaire were prepared in English and subsequently translated into Papiamento by Kevin Orozco Mendoza, a native speaker of Papiamento from Aruba.

2.1. Participants

The inclusion criteria for participation in the current study were the following:

- age between 5 and 7 years;
- no diagnosed or suspected cognitive disability;
- no intelligence deficit;
- enrollment in Aruban pre-school or elementary education.

Assessment of cognitive disabilities and intelligence deficits was based on assessments by teachers and other specialized professionals. Additionally, subjects were divided into two groups: one composed of participants affected by DLD (DLD group), and a control group, composed of typically developing children (TD group). A diagnosis of DLD from an SLP was necessary for inclusion in the DLD group.

Parents of pupils registered at the Bureau Multidisciplinair Centrum (MdC) were contacted by the Bureau, regardless of whether the child had already undergone speech therapy or not. They were introduced to the present study and asked for preliminary consent for their child to take part in the investigation. Following this conversation, the researcher contacted the school boards of the students whose parents had agreed. Principals and teachers were asked for collaboration to carry out the investigation on school premises and during school hours, and to provide parents with the information letter and consent form. If consent was given from all parties involved, the testing session would be scheduled at school during school hours, to be the least disruptive to educational activities.

For the DLD group, MdC received parental consent for 11 pupils (9 males, 2 females), attending 9 different schools in various locations around Aruba, thus representing all areas of the island. 6 school boards gave consent, and 7 participants have been administered the CL-NWR test. The relevant data is listed in Table 1. One subject (14%) was female, the other 6 (86%) were males. The average age was 6;5.

Table 1. The participants in the DLD group.

	Age	Age first word	Speech-language therapy started
15	6;6	2;0-2;11	Yes
14	6;4	2;0-2;11	Yes
12	5;8	3;0-3;11	No
13	6;8	1;0-1;11	No
11	6;10	1;0-1;11	Yes
17	6;8	2;0-2;11	Yes
111	6;7	1;0-1;11	Yes

For the final version of this paper, data will be collected from a TD group: 4 school boards, different from the ones attended by the DLD group, and 3 after-school care centers were contacted via email to introduce the study. These were asked whether their institution would participate by approaching parents of TD pupils and consenting to testing sessions taking place on school premises and during school hours. Only 1 school board, and no after-school center, agreed to participate.

2.2. Test materials

2.2.1. LITMUS CL-NWR test

The LITMUS CL-NWR test was employed, comprising 2 practice items and 16 test items presented in a fixed predetermined order. All items were assessed by a native speaker of Papiamento from the MdC, with advanced knowledge of Dutch, Spanish, and English, and working with patients from different linguistic backgrounds, thus having rudimentary knowledge of phonetic inventories and rules of other languages spoken by participants. The final list of test items is presented in Table 2 in the order in which they are presented to the participants. Items number 3 ([li'i'sa'ku]), 4 (['ma'li'tu]), and 11 (['ma'lu'si'ku'pa]) were substituted with one of the provided alternative recordings due to close resemblance to existing Papiamento words.

Table 2. Numbered items chosen for the CL-NWR administered in the current study.

	Item		*Item*		*Item*		*Item*
1	dula	**5**	zibu	**9**	sipula	**13**	lumiga
2	bamudi	**6**	mukitala	**10**	sipalita	**14**	litapimuti
3	litizaku	**7**	sipumakila	**11**	maluziguba	**15**	duligasumu
4	nalidu	**8**	nuli	**12**	kasulumi	**16**	nagi

2.2.2. PaBiQ questionnaire

The PaBiQ questionnaire was adapted to the current study and to the most common languages spoken in Aruba, namely Papiamento, Spanish, English, Dutch, and Chinese. The final version included 41 questions. Parents were given the questionnaire with the consent form and information letter by the school and were asked to fill it out before the scheduled testing session. Questions were available in Papiamento and English. One parent asked to be assisted by their child's teacher in filling out the PaBiQ due to the language barrier.

2.3. Data collection

2.3.1. LITMUS CL-NWR test

Testing took place in quiet non-soundproof rooms on school premises, in some cases in the presence of a teacher to ensure participants were as comfortable as possible. The test was presented on a laptop screen and administered in either English or Spanish, depending on the language the participant was most comfortable in. Following the procedure designed by Polišenská & Kapalková (2014), a story was told to gamify the task as if each repeated item would fix part of a broken beaded necklace. The two practice items were repeated until the child understood the procedure. Test items were presented only once and participants were praised, regardless of whether the response was correct or not. Children's repetitions were recorded via the open-access software Praat version 6.4.27 (Boersma & Weenink, 2025) running on a LENOVO 80Y7 laptop with an Intel Core i5-8250U processor, using Windows 11.

2.3.2. PaBiQ questionnaire

Once filled out by the parents, the questionnaire was sent to the researcher via email or hand-delivered on the day of the testing session, together with the signed informed consent form.

2.4. Data analysis

2.4.1. LITMUS CL-NWR test

Each participant was assigned a randomly generated number between 1 and 20, preceded by a code, to ensure anonymity during data analysis and reporting.

Participants' repetitions were scored offline following the procedure described by Chiat et al (2020). Recordings were transcribed through Praat (Boersma & Weenink, 2025). The number and percentage of whole items correctly repeated was chosen as the dependent variable of the present study. Whole item scoring is considered more promising than segment scoring for clinical application, as it is sufficiently discriminating, quicker, and more practical (Chiat, 2015; Chiat & Polišenská, 2016). For the final version of this paper, segment scoring will also be carried out, thus providing data for the comparison of scoring methods.

To be scored correct, repetitions needed to contain all and only the segments in the model items in the correct order. Segments were correct if they were perceived as falling within the target category: correct voicing, place, and manner of articulation for consonants; correct height, backness, and lip rounding for vowels. Spectral analysis was employed in case of uncertainty to assess the characteristic of the produced phoneme. Non-responses, omissions, substitutions, and additions were scored as incorrect. On the other hand, changes in prosody, systematic substitutions, and intermediate realization of segments were scored as correct. That is to say, a change in stress, a continuous and predictable substitution, or the production of an ambiguous sound that could fall within the target category were all considered correct.

The maximum possible score was 16. Before the final version of the paper, a second independent rater will score part of the data to ensure inter-rater reliability and agreement.

Preliminary observations were made to identify patterns in the data collected from the DLD group. Trends were compared to those reported in previous studies, allowing for a preliminary assessment of whether the observed patterns aligned with existing literature on bilingual populations.

Participants were divided into two groups based on whether they had already started a speech-language therapy process or not. Scores from the two groups were compared to assess the effect of speech-language therapy on nonword repetition performance.

Participants were divided into three groups based on when they pronounced their first words (one, two, or three years of age), to assess whether this is an indicator of DLD in multilingual children.

Once data collection is complete, statistical analyses will be conducted via the open-access software JASP version 18.3 (JASP Team, 2023). Due to small sample size and possible high variability in the data, non-parametric tests will be employed. Mann-Whitney U tests will be used to compare DLD and TD groups on non-word repetition performance, as well as older (6;7 to 7;0) and younger (5;0 to 6;6) participants within the two groups. Friedman tests will compare performance across different word lengths within the DLD and TD groups, to determine whether one group had more difficulties with longer or shorter items. Post-hoc pairwise comparisons will follow up statistically significant results to identify which specific conditions differed.

2.4.2. PaBiQ questionnaire

Data collected from the parental questionnaire was not analyzed independently, since the aim of the current study was to assess the CL-NWR task rather than the questionnaire itself. However, the linguistic background and family history of each participant, gathered via this questionnaire, was taken into consideration when analyzing findings from the CL-NWR test.

3. Preliminary results

Scores are reported in Table 3 and coded as "0" if the repetition was incorrect and "1" if the item was repeated correctly. Totals per item are listed in the right-most column and totals per participant in the last row.

Table 3. Participants' scores in the CL-NWR task. Repetitions are coded as 0 if incorrect and 1 if correct.

	Participant							
	15	*14*	*12*	*13*	*11*	*17*	*111*	***Total***
Item 1	**1**	**1**	0	0	0	**1**	0	**3**
Item 2	0	0	0	0	0	0	0	**0**
Item 3	0	0	0	0	**1**	0	0	**1**
Item 4	**1**	0	**1**	0	**1**	0	0	**3**
Item 5	**1**	0	0	**1**	**1**	0	0	**3**
Item 6	**1**	0	0	0	**1**	**1**	**1**	**4**
Item 7	0	0	0	0	0	0	0	**0**
Item 8	0	0	0	0	0	0	0	**0**
Item 9	**1**	**1**	0	**1**	0	**1**	**1**	**5**
Item 10	0	**1**	0	**1**	**1**	0	0	**3**
Item 11	0	0	0	0	0	0	0	**0**
Item 12	**1**	**1**	0	**1**	**1**	**1**	**1**	**6**
Item 13	**1**	0	0	**1**	0	**1**	**1**	**4**
Item 14	0	0	0	0	0	0	0	**0**
Item 15	0	0	0	**1**	0	0	0	**1**
Item 16	**1**	**1**	0	**1**	**1**	**1**	**1**	**6**
Total	**8**	**5**	**1**	**7**	**7**	**6**	**5**	

The data from Table 3 is summarized in the graphs in Figure 2 and Figure 3, respectively showing the accuracy rate against age and item-length.

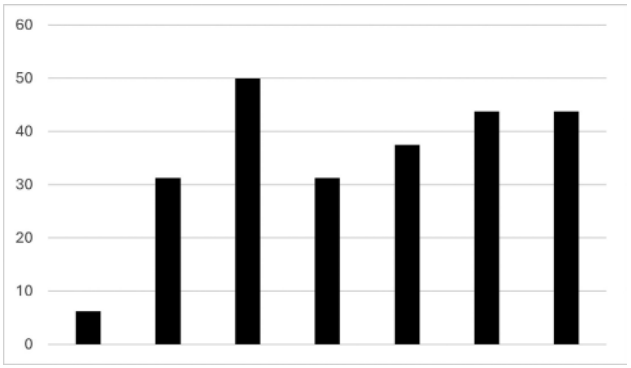

Figure 2. Nonword repetition accuracy rate (%) (y-axis) against age (x-axis) in children with DLD.

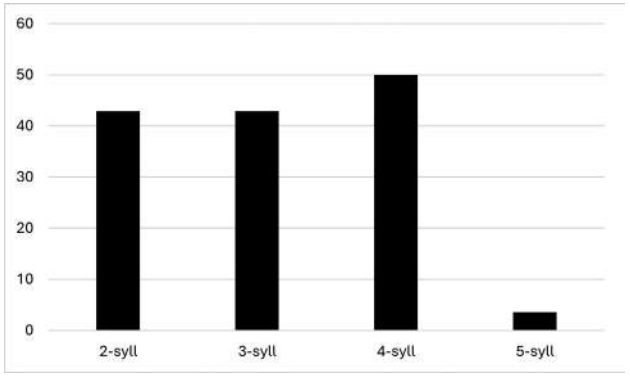

Figure 3. Nonword repetition accuracy rate (%) (y-axis) against item-length in syllables (x-axis) in children with DLD.

On average, participants affected by DLD scored 5.6 out of 16 total possible points, meaning 5.6 items were repeated correctly out of the 16 presented, thus leading

to 35% accuracy rate. As shown in Figure 2, the lowest score was 1 (6.25% accuracy), associated with the youngest participant, and the highest score was 8 (50% accuracy), reached by older participants, although not by the oldest.

Five items were not repeated correctly by any child, namely items 2 (/bamudi/), 7 (/sipumakila/), 8 (/nuli/), 11 (/maluziguba/), and 14 (/litapimuti/). Items 3 (/litizaku/) and 15 (/duligasumu/) were correctly repeated by only one participant each amongst the two oldest participants. Items 1 (/dula/), 4 (/nalidu/), 5 (/zibu/), and 10 (/sipalita/) were correctly repeated by three participants each. Items 6 (/mukitala/) and 13 (/lumiga/) were correctly repeated by four participants each, while item 9 (/sipula/) was repeated correctly by five participants. Items 12 (/kasulumi/) and 16 (/nagi/) were each repeated correctly by six participants.

In total, 12 points were scored by the DLD group in two-syllable items out of the 28 possible points. In the same way, 12 points were scored in three-syllable items and 14 in four-syllable items. On the other hand, only 1 point was scored in five-syllable items, by the second oldest child. As illustrated in Figure 3, this translates to an overall accuracy of 43% for two-syllable items, 43% for three-syllable items, 50% in four-syllable items, and 4% in five-syllable items.

Figure 4 shows the average accuracy rate of the participants that had already started a speech-language therapy process and of those that had not. On average, the former groups scored 6.2 (38.75%) and the latter 4 out of 16 (25%).

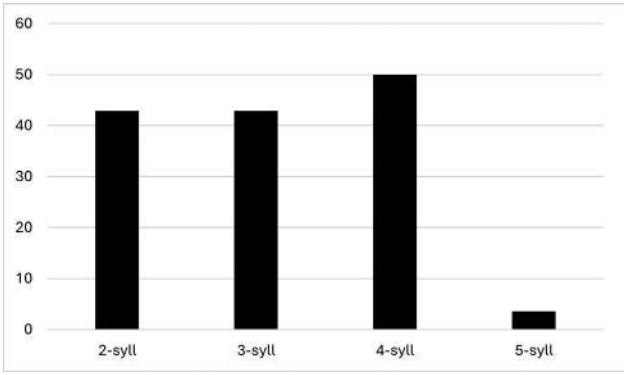

Figure 4. Nonword repetition accuracy rate (%) (y-axis) of children with DLD that started (left) and did not start (right) a speech-language therapy process.

Figure 5 shows the accuracy rate of the participants on the basis of the age at which they pronounced their first words, as reported by parents via the PaBiQ. On average, the children in the 1-year-old group repeated 1 out of 16 items correctly (37.5%), while the 2-year-old group scored 6 out of 16 (43.6%) and the 3-year-old group scored 1 (6.25%).

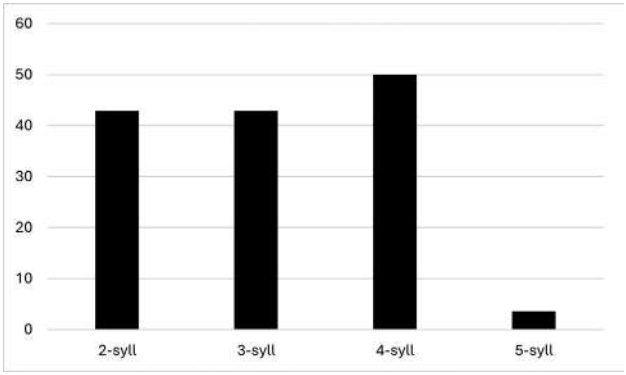

Figure 5. Nonword repetition accuracy rate (%) (y-axis) of children with DLD that pronounced their first words at 1- (left), 2- (middle), and 3-years-old (right).

4. Discussion

This discussion looks at the collected data focusing on RQ 1, 3, and 4 guiding the current study. First, it considers how multilingual children with DLD performed on the CL-NWR task, analyzing the effects of age and item-length (RQ 1). Then, these findings are compared to previous research carried out amongst bilingual populations employing the same task (RQ 3). Lastly, it assesses the clinical applicability of the CL-NWR test in multilingual settings (RQ 4).

4.1. Preliminary interpretation of results

The data collected allows for discussion of the effects of participant's age and item length on NWR performance.

The scores and accuracy rates suggest that the latter is positively correlated with age, since the youngest participant showed the lowest accuracy, as illustrated in Figure 2. However, a plateau seems to exist as no participant scored higher than 8 (50%). Also, almost no difference in overall accuracy emerged between two-, three-, and four-syllables items, ranging from 43% to 50%. This is not the case for five-syllable items, which were repeated with an overall accuracy of 4%.

Some items proved more challenging than others. Items 7 (/sipumakila/), 11 (/maluziguba/), and 14 (/litapimuti/) are five-syllables long and were not repeated correctly by any child, thus supporting the previous statement of longer items being harder to repeat. In addition, items 3 (/litizaku/) and 15 (/duligasumu/), four- and five-syllables long respectively, were repeated correctly only by the older participants. However, items 2 (/bamudi/) and 8 (/nuli/) are only three- and two-syllables long, and they still prove challenging. On the other hand, items 12 (/kasulumi/) and 16 (/nagi/) seem the easiest, being four- and two-syllables long respectively. Therefore, these findings seem to contradict the idea that accuracy is negatively correlated with item length, except when it concerns five-syllables long nonwords, which might be explained by the small vSTM span of 5-to-7-year-olds, regardless of LIs. Also, the phonemes and segments included in the items, together with the individual's linguistic repertoire, might play a role in the accuracy rates: if the sounds and sequences are familiar to the child, repetition is more likely to be correct.

The high individual variation of the data collected was examined from different perspectives. Firstly, the participants who had already started a speech-language therapy process performed better than those that did not, as shown in Figure 4. This suggests a positive effect of the intervention of an SLP. Secondly, the participant whose parents reported pronounced their first words at 3-years-old scored lower than their peers. This could be explained by the participant being the youngest in the sample, although it aligns with previous studies identifying late language onset as marker for DLD (Boerma & Blom, 2017) Interestingly, by investigating the linguistic background of the highest scoring participant, it emerges that they are the one most often exposed to the most languages. They carry out activities in Papiamento, English, Dutch, and Spanish over a typical week and interact with their parents in all the languages they are acquiring. This finding is particularly important in the support of multilingualism as it does not align with the inaccurate assumption that the acquisition of multiple languages is detrimental to the child.

Analyzing in more detail each participant's performance, common patterns can be observed: lexicalization bias, systematic substitutions, and practice effect.

Lexicalization bias was observed in all participants for at least one item. For instance, item 6 (/mukitala/) was repeated by various participants as /bukitala/, containing the Papiamento word "buki" which translates to "book". Interestingly, those that were replaced with alternative recordings, were often mispronounced in a way that closely resembled the original version. For instance, item 3 (/litizaku/) was repeated by various subjects as /litisaku/, which contains the Papiamento word "saku" translating to "bag".

Four participants exhibited systematic substitutions of the phoneme /z/, which was realized as /s/ in all items. Also, /s/ was pronounced as /θ/ by one subject, as well as /l/ substituted by /n/ by another child. This could suggest the phoneme /s/ being particularly challenging for Aruban children with DLD.

The practice effect was observed in three participants whose performance improved as the task progressed. This could be explained by a variety of factors, such as better understanding of the task or participants being more comfortable in the testing environment.

4.2. Comparison with previous research

The data collected was compared to the findings from previous research (Boerma et al., 2015; Hamdani et al., 2024; Öberg & Bohnacker, 2024; Schwob & Skoruppa, 2022) to determine whether this multilingual population affected by DLD exhibits the same performance as bilingual populations with the same condition.

The average score (5.6) and accuracy rate (35%) found in the current study are in agreement with, although slightly higher than, those reported by previous research. For instance, Hamdani et al. (2024)found an average score of 3, corresponding to 18.75% accuracy, in a case study of an Urdu-Cantonese bilingual child with DLD. Similarly, Boerma et al. (2015) reported a score of 4, or 28.6% accuracy, from a study on bilingual children who spoke Dutch and another minority language, such as Turkish, and Moroccan Arabic. Schwob and Skoruppa (2022) found an average score of 5, or 31.25% accuracy, in a study on French-Portuguese bilinguals.

In addition, performance appears to improve with age and the longest items seem the most challenging. This resembles the findings of previous research, which suggest that longer words are more difficult for all children, but those affected by DLD make more errors in items with fewer syllables as well (Öberg & Bohnacker, 2024; Schwob & Skoruppa, 2022). The identified accuracy rate of 43% for two-syllable items is in accordance with previous findings, although three- and four-syllable items did not prove more complicated for the participants of the current study, which is contrary to pre-existing literature (Boerma et al., 2015; Schwob & Skoruppa, 2022).

Ultimately, although the sample size is small, the collected data aligns with the average findings on bilinguals' performance in the CL-NWR task as presented by previous literature. Based on these results, participants of the DLD group would likely be correctly identified as being affected by DLD through this test. While preliminary, these findings suggest that the CL-NWR could be a promising assessment tool in Aruba, since its outcomes seem to converge with SLPs' assessments.

4.3. Limitations

Limitations of the current study come from the nature of the CL-NWR task and the PaBiQ, as well as from the study design and participants' recruitment procedure.

Firstly, despite the set of options offered for each item, it can be argued that the CL-NWR test cannot be truly language-neutral. This test was designed to include phonemes, syllable structures, and prosody shared by several languages. However, items may still be more similar to real words in some languages than others and, thus, easier to repeat or more likely to be subject to lexicalization by speakers of these languages. For instance, the syllable structure used for all items is inherently more characteristic of certain languages. In the same way, the patterns of vowels and consonants included in the CL-NWR test might be more common in real words of certain languages. As for the PaBiQ, the background information obtained this way might be incorrect or biased by parents' opinions, desires, and memories. For instance, some participants were reported as having never been exposed to English, while teachers suggested the test be administered

in English, as they believed it was the participants' most comfortable language after Papiamento. This might be related to cultural habits. Indeed, it was pointed out by people embedded in Aruban society that teachers are often those spending more time with the child and talking to them the most. Therefore, they may be the most aware of the pupil's language development.

In addition, the very limited sample size does not allow for statistical analysis and for significant observations to be drawn. Also, 86% of the participants were males: although not providing a good representation of the whole Aruban population, this fits, to an extent, with the population prevalence of DLD and it partly depends on the recruitment method. Moreover, the DLD group was not further divided based on the different types of DLD. DLD subtypes have been identified depending on what linguistic domain is affected: phonological, expressive, mixed expressive-receptive (Casalini et al., 2007). Although different types of DLD have been shown to differ in accuracy of their repetition performance, and thus memory abilities, no distinction was taken into consideration for the present study, due to time constraints and lack of resources. Additionally, the assessment by SLP was taken into consideration when recruiting participants: the possibility of misdiagnosis was not accounted for. Hence, the heterogeneity and uncertainty of the DLD diagnosis could have been a source of individual variation (Öberg & Bohnacker, 2024).

Regarding the scoring procedure, the phonetic transcription of participants' repetitions was carried out by a native speaker of Italian, with advanced proficiency in English and intermediate proficiency in Spanish. This might have affected the perception of produced phonemes, especially if non-existent in the languages known by the scorer or ambiguous. Although spectral analysis was employed to mitigate this risk, scoring might remain biased by the scorer's native language. Also, segment scoring usually provides a more accurate measure of performance than whole item scoring, thus being more reliable.

4.4. Further research

Following this exploratory study, more research should be carried out in Aruba, as well as amongst other multilingual populations. This should include a bigger sample and population-based studies. The reliability of other tests of the LITMUS battery should be investigated, and further data should be gathered for norm-referencing. For starters, the combination of PaBiQ, CL-NWR, and MAIN tasks could be explored, as suggested by Boerma & Blom (2017). Additionally, the CL-NWR task could be refined in light of the insights and observations shared in this paper. For instance, the order of presentation of the items could be randomized to avoid any possible practice effect. Also, more two-, three-, and four-syllables items could be included since five-syllables items seem to be challenging for all children.

5. Conclusion

Overall, the findings of the current study align with previous literature and converge with SLPs' assessments, suggesting that the CL-NWR test, and possibly the whole LITMUS battery, could be employed in Aruba as standard a diagnostic method for DLD. This should still be interpreted in light of a full picture of a multilingual child's language skills and difficulties, gathered, for instance, through the PaBiQ or other processing-oriented assessments, to minimize the impact of the individual's unique background. The data from the control group, to be collected for the final publication, will be crucial in establishing whether the challenges faced by Aruban children with DLD are shared by their typically developing peers or if they are, indeed, related to their language impairment.

For the further development of the LITMUS test battery, contributions of reference data from both typically developing and DLD multilinguals are needed for the evaluation of the tools. In Aruba, we are only at the beginning, and this study is one such contribution.

References

- American Psychiatric Association. (2022). Diagnostic and statistical manual of mental disorders (5th ed., text rev.). https://doi.org/10.1176/appi.books.9780890425787
- Archibald, L. M. D., & Gathercole, S. E. (2006). Nonword Repetition: A Comparison of Tests. Journal of Speech, Language, and Hearing Research, 49(5), 970–983. https://doi.org/10.1044/1092-4388(2006/070)
- Armon-Lotem, S., & Grohmann, K. K. (2021). Introduction. In S. Armon-Lotem & K. K. Grohmann (Eds.), Language Impairment in Multilingual Settings : LITMUS in Action Across Europe (1st ed., Vol. 29, pp. 1–9). John Benjamins Publishing Company. https://doi.org/10.1075/tilar.29.int
- Baird, G. (2008). Assessment and investigation of children with developmental language disorder. In C. Frazier Norbury, J. B. Tomblin, & D. V. M. Bishop (Eds.), Understanding Developmental Language Disorders: From Theory to Practice (1st ed., pp. 1–22). Psychology Press. https://doi.org/https://doi-org.utrechtuniversity.idm.oclc.org/10.4324/9780203882580
- Baker, C. ., & Jones, S. P. . (1998). Bilingualism and learning difficulties. In Encyclopedia of bilingualism and bilingual education. Multilingual Matters.
- Boerma, T., & Blom, E. (2017). Assessment of bilingual children: What if testing both languages is not possible? Journal of Communication Disorders, 66, 65–76. https://doi.org/10.1016/j.jcomdis.2017.04.001
- Boerma, T., Chiat, S., Leseman, P., Timmermeister, M., Wijnen, F., & Blom, E. (2015). A Quasi-Universal Nonword Repetition Task as a Diagnostic Tool for Bilingual Children Learning Dutch as a Second Language. Journal of Speech, Language, and Hearing Research, 58(6), 1747–1760. https://doi.org/10.1044/2015_JSLHR-L-15-0058
- Boersma, P., & Weenink, D. (2025). Praat: Doing phonetics by computer (Version 6.4.27) [Computer software]. https://www.praat.org/
- Campbell, T., Dollaghan, C., Needleman, H., & Janosky, J. (1997). Reducing Bias in Language Assessment. Journal of Speech, Language, and Hearing Research, 40(3), 519–525. https://doi.org/10.1044/JSLHR.4003.519
- Casalini, C., Brizzolara, D., Chilosi, A., Cipriani, P., Marcolini, S., Pecini, C., Roncoli, S., & Burani, C. (2007). Non-word repetition in children with specific language impairment: a deficit in phonological working memory or in long-term verbal knowledge? Cortex; a Journal Devoted to the Study of the Nervous System and Behavior, 43(6), 769–776. https://doi.org/10.1016/S0010-9452(08)70505-7
- Centraal Bureau voor de Statistiek Aruba. (2020). Quarterly Demographic Bulletin - 3rd quarter 2020. Aruba.
- Centraal Bureau voor de Statistiek Aruba & Dienst Burgerlijke Stand en Bevolkingsregister Aruba. (2023). Immigration to Aruba in the Last 50 Years. Aruba.
- Chiat, S. (2015). Non-word repetition. In S. Armon-Lotem, J. de Jong, & N. Meir (Eds.), Methods for assessing multilingual children: Disentangling bilingualism from language impairment (pp. 125–150). Multilingual Matters.
- Chiat, S., & Polišenská, K. (2016). A framework for crosslinguistic nonword repetition tests: Effects of bilingualism and socioeconomic status on children's performance. Journal of Speech, Language, and Hearing Research, 59(5), 1179–1189. https://doi.org/10.1044/2016_JSLHR-L-15-0293
- Chiat, S., Polišenská, K., Yanushevskaya, I., & Antonijevic, S. (2020). Language Neutral Crosslinguistic Nonword Repetition Test (CL-NWR).
- Collée, E. (2018). A New Dutch Non-Word-Repetition Task to Test the Production of Consonant Clusters With and Without /s/ by TD Dutch Children [Research Master's Thesis]. Utrecht University.
- Faraclas, N., Kester, E. P., & Mijts, E. (2019). Community Based Research in Postcolonial Communities. Language Policy(Netherlands), 20, 7–20. https://doi.org/10.1007/978-3-030-23223-8_2

- Felix. (2023, March 27). Modelo di educacion hulandes no ta adapta na e necesidadnan local, segun UNESCO. Diario Online. https://diario.aw/categories/noticia/general/modelo-di-educacion-hulandes-no-ta-adapta-na-e-necesidadnan-local-segun-unesco
- Felix. (2024, March 8). Alumnonan di Klas 1 lo siña lesa y skirbi na Papiamento entrante augustus 2024. Diario Online. https://diario.aw/categories/noticia/general/alumnonan-di-klas-1-lo-sina-lesa-y-skirbi-na-papiamento-entrante-augustus-2024
- Gillam, S. L., Holbrook, S., & Kamhi, A. G. (2021). Developmental Language Disorder. In The Handbook of Language and Speech Disorders (pp. 171–191). wiley. https://doi.org/10.1002/9781119606987.ch9
- Hamdani, S., Chan, A., Kan, R., Chiat, S., Gagarina, N., Haman, E., Łuniewska, M., Polišenská, K., & Armon-Lotem, S. (2024). Identifying developmental language disorder (DLD) in multilingual children: A case study tutorial. International Journal of Speech-Language Pathology. https://doi.org/10.1080/17549507.2024.2326095
- International Expert Panel on Multilingual Children's Speech (IEPMCS). (2012). Multilingual children with speech sound disorders: Position paper. Research Institute for Professional Practice, Learning and Education, Charles Sturt University.
- JASP Team. (2023). JASP (Version 18.3) [Computer software]. https://jasp-stats.org/
- Lo-Fo-Sang, K. (2022). The Current Context of the Language of Instruction in Aruban Education: Towards a more inclusive Multilingual Education [Master Thesis]. University of Utrecht.
- Meir, N. (2021). Effects of Specific Language Impairment (SLI) and bilingualism on verbal short-term memory. In S. Armon-Lotem & K. K. Grohmann (Eds.), Language Impairment in Multilingual Settings : LITMUS in Action Across Europe (1st ed., Vol. 29, pp. 198–225). John Benjamins Publishing Company. https://doi.org/10.1075/tilar.29.07mei
- Mijts, E., Kester, E.-P., & Faraclas, N. (2018). Multilingualism and education in the Caribbean Netherlands: a community based approach to a sustainable language education policy. The case study of St. Eustatius.
- Nudel, R., Christensen, R. V., Kalnak, N., Schwinn, M., Banasik, K., Dinh, K. M., Erikstrup, C., Pedersen, O. B., Burgdorf, K. S., Ullum, H., Ostrowski, S. R., Hansen, T. F., & Werge, T. (2023). Developmental language disorder – a comprehensive study of more than 46,000 individuals. Psychiatry Research, 323, 115171. https://doi.org/10.1016/j.psychres.2023.115171
- Öberg, L., & Bohnacker, U. (2024). Beyond Language Scores: How Language Exposure Informs Assessment of Nonword Repetition, Vocabulary and Narrative Macrostructure in Bilingual Turkish/Swedish Children with and without Developmental Language Disorder. Children, 11(6). https://doi.org/10.3390/children11060704
- Ortiz, J. A. (2021). Using nonword repetition to identify language impairment in bilingual children: A meta-analysis of diagnostic accuracy. American Journal of Speech-Language Pathology, 30(5), 2275–2295. https://doi.org/10.1044/2021_AJSLP-20-00237/ASSET/675D4241-B98F-4A45-B4C2-C0EA406574EC/ASSETS/GRAPHIC/AJSLP-20-00237FIG3.JPG
- Paradis, J. (2011). Individual differences in child English second language acquisition. Linguistic Approaches to Bilingualism, 1(3), 213–237. https://doi.org/10.1075/lab.1.3.01par
- Schwob, S., Eddé, L., Jacquin, L., Leboulanger, M., Picard, M., Oliveira, P. R., & Skoruppa, K. (2021). Using Nonword Repetition to Identify Developmental Language Disorder in Monolingual and Bilingual Children: A Systematic Review and Meta-Analysis. Journal of Speech, Language, and Hearing Research, 64(9), 3578–3593. https://doi.org/10.1044/2021_JSLHR-20-00552
- Schwob, S., & Skoruppa, K. (2022). Detecting Developmental Language Disorder in Monolingual

and Bilingual Children: Comparison of Language-Specific and Crosslinguistic Nonword Repetition Tasks in French and Portuguese. Journal of Speech, Language, and Hearing Research, 65(3), 1159–1165. https://doi.org/10.1044/2021_JSLHR-21-00017

- Sollie, F. (2015). Language and education in a multilingual society: Text comprehension and language attitudes among Aruban high school students [Bachelor's Thesis]. University of Utrecht.
- Tribushinina, E., Dubinkina-Elgart, E., & Rabkina, N. (2020). Can children with DLD acquire a second language in a foreign-language classroom? Effects of age and cross-language relationships. Journal of Communication Disorders, 88, 106049. https://doi.org/10.1016/J.JCOMDIS.2020.106049
- Tuller, L. (2015). Clinical Use of Parental Questionnaires in Multilingual Contexts. In S. Armon-Lotem, J. De Jong, & N. Meir (Eds.), Assessing Multilingual Children: disentangling bilingualism and language impairment. Multilingual Matters. https://doi.org/https://doi.org/10.21832/9781783093137-013
- UCL. (2024). Adult DLD Assessment Service (ADAS). UCL Psychology and Language Sciences. https://www.ucl.ac.uk/pals/adult-dld-assessment-service-adas
- Vance, M. (2008). Short-term memory in children with developmental language disorder. In C. Frazier Norbury, J. B. Tomblin, & D. V. M. Bishop (Eds.), Understanding Developmental Language Disorders From Theory to Practice (1st ed., pp. 23–38). Psychology Press. https://doi.org/https://doi-org.utrechtuniversity.idm.oclc.org/10.4324/9780203882580
- Wouda, L., Boerma, T., Gerrits, E., & Blom, E. (2024). First Steps Toward Implementation of the Online Test Battery LITMUS-NL: A Usability and Feasibility Study. Perspectives of the ASHA Special Interest Groups, 9(5), 1439–1455. https://doi.org/10.1044/2024_PERSP-23-00308

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I wove into the paper's vision of reinvesting carbon credit proceeds into sustainable initiatives.

The course *Interdisciplinary, Multidisciplinary Approaches to Sustainable Development* has been a transformative experience, deeply influencing the direction of my research paper on tokenizing carbon credits for a circular economy in Aruba. Coming into the course, I was aware of the pressing environmental challenges faced by small island developing states (SIDS) like Aruba, particularly their vulnerability to climate change and economic dependence on tourism. However, the interdisciplinary lens of the course broadened my perspective, encouraging me to integrate diverse fields such as blockchain technology, sustainability, and economic systems to address these challenges holistically. One of the most impactful aspects of the course was its emphasis on the interconnectedness of ecological, social, and economic systems, especially in the context of islands. Learning about planetary boundaries through the island metaphor resonated with me—it highlighted the finite nature of resources and the urgent need for innovative solutions that balance ecological limits with human wellbeing. This perspective inspired me to focus on a circular economy framework for Aruba, where waste minimization and resource efficiency could be prioritized. The course's exploration of doughnut economics further reinforced this idea, showing me how Aruba could meet its population's needs while staying within ecological boundaries, a concept I wove into the paper's vision of reinvesting carbon credit proceeds into sustainable initiatives.

The multidisciplinary approach of the course also pushed me to combine my knowledge of blockchain technology with sustainability goals. Discussions on socio-metabolic risk and climate change in small island states revealed the complexity of these challenges, particularly for tourism-driven economies like Aruba's. This led me to explore how blockchain could democratize access to carbon markets for SIDS, an idea that became the cornerstone of my paper. The

course's focus on linguistic and cultural diversity in islands also influenced my thinking—I realized that any solution for Aruba needed to be culturally sensitive and engage local stakeholders, prompting me to design a system where tourists, businesses, and residents could all participate in a tokenized carbon credit market. A key moment in the course was learning about the role of technology in sustainable development. While I was already familiar with blockchain from my studies, the course introduced me to practical applications like Digital Monitoring, Reporting, and Verification (D-MRV) systems and their potential to ensure transparency in emissions tracking. This inspired me to integrate a D-MRV framework with the XRP Ledger (XRPL) in my paper, creating a system where emissions reductions could be accurately monitored, tokenized, and traded as NFTs. The course's emphasis on collaboration across disciplines gave me the confidence to bridge these technical concepts with Aruba's Circular Economy Vision 2050, ensuring my proposal was both innovative and grounded in local needs. Reflecting on the course, I'm struck by how it encouraged me to think beyond siloed solutions. The interdisciplinary approach taught me to see Aruba not just as a case study, but as a microcosm of global sustainability challenges. By combining insights from ecology, economics, technology, and cultural studies, I was able to develop a paper that not only addresses Aruba's specific needs but also offers a scalable model for other SIDS. This course has inspired me to continue exploring how technology and interdisciplinary thinking can drive sustainable development, and I'm eager to see how these ideas can be applied in real-world contexts.

Tokenizing Carbon Credits for a Circular Economy in Small Island States

Interdisciplinary Multidisciplinary Approaches to Sustainable Development

Josua Frias

Abstract

Aruba, a small island state in the Caribbean, faces substantial environmental and economic pressures due to its dependence on tourism and dependence on imported resources. Amid global efforts to combat climate change, tokenizing carbon credits using blockchain technology presents an opportunity to advance sustainability within Aruba's economy. This paper explores how this approach, specifically leveraging a Digital - Monitoring, Reporting & Verification (D-MRV) system framework & the XRP Ledger (XRPL), could support the development of a circular economy in Aruba, a system aimed at minimizing waste and maximizing resource efficiency. It examines the concept of tokenized carbon credits, their potential benefits and challenges within the context of a small island, and proposes a practical framework for implementation, aligning with Aruba's sustainability goals outlined in its Circular Economy Vision 2050.

1. Introduction

Small island developing states (SIDS) occupy a special position in the global landscape of climate change, subject to quite some vulnerabilities despite contributing a tiny fraction of global greenhouse gas emissions. Island nations, often characterized by limited landmass, isolated geographies, and fragile ecosystems, face existential threats from rising sea levels, intensified storms, and shifting climatic patterns (United Nations Framework Convention on Climate Change (UNFCCC), 2021). Their economies, heavily reliant on climate-sensitive sectors such as tourism and fisheries, are particularly susceptible to environmental disruptions, making paths to resilience an urgent priority. Compounding these challenges is restricted access of small island to global capital markets and technical expertise, which disrupts their capacity to meet international sustainability targets, like those in the Paris Agreement. Circular economy principles focused on resource efficiency, waste reduction, and regenerative systems offer a transformative pathway for SIDS to enhance sustainability while fostering economic autonomy. Within this context, carbon credit markets present both a challenge and a significant opportunity for SIDS. Carbon credits are certificates representing the avoidance or removal of the equivalent of one metric ton of CO2 these are typically traded through entralized systems dominated by large economies and corporations. High entry barriers and complex verification processes currently limit the participation of SIDS in global carbon markets (World Bank, 2022). However, the rise of blockchain technology has introduced a disruptive innovation: the tokenization of carbon credits. Tokenization would involve the conversion of carbon credits into digital assets recorded on a blockchain, enabling transparent, efficient, and decentralized trading. This approach promises to democratize access to carbon

markets, aligning with circular economy goals by integrating sustainability into economic transactions and incentivizing emissions reductions at a local level.

Blockchain, at its core, is a decentralized digital ledger that records transactions across a network of computers in a secure, transparent, and immutable manner (Narayanan et al., 2016). Unlike traditional databases managed by a single authority, blockchain operates without intermediaries, relying on cryptographic techniques to ensure data integrity and consensus protocols to validate entries. Each transaction, termed a "block", is linked to the previous one, forming a chronological "chain" that cannot be altered retroactively without network consensus. This technology underpins cryptocurrencies like Bitcoin, but its applications extend far beyond those, offering a robust framework for managing other digital assets like tokenized carbon credits. By recording carbon credits on a blockchain, tokenization ensures that each credit's origin, ownership, and retirement status are transparently tracked, reducing the risk of double-counting or fraud. Furthermore, blockchain's efficiency, enabled by rapid transaction processing and low operational costs, makes it feasible for smaller entities, including SIDS, to participate in carbon markets without the immense expenses of traditional systems (World Economic Forum, 2021).

This paper explores the integration of tokenized carbon credits into SIDS economies, emphasizing how blockchain technology can facilitate this process and align with circular economy objectives. By leveraging blockchain's capabilities, SIDS can transform carbon credits from abstract certificates into accessible digital tokens, tradable on global platforms or within localized markets, thereby generating revenue to fund sustainable initiatives. The paper adopts an exploratory approach, synthesizing existing literature to assess the potential of this innovation, with a particular focus on Aruba as a case sttudy. The paper reviews relevant literature and case studies that show how blockchain technology can be used for carbon credits. It covers examples and ideas from past research that highlight the benefits and challenges of this approach. Then it discusses how blockchain application could be put into practice in Aruba and other Small Island Developing State (SIDS) to track and manage carbon credits, supporting their efforts to address climate change and improve sustainability and how this bring about a circular economy.

1.1 The Case for Aruba

Aruba, a Caribbean Island spanning 180 square kilometers, exemplifies the challenges and opportunities inherent to small island states. Aruba's economy is overwhelmingly dependent on tourism, which contributes over 80% of GDP and attracts more than one million visitors annually (UNWTO, 2021). Tourism is responsible for asignificant portion of energy consumption and CO2 emissions, and necessitates heavy reliance on imported goods. This includes the fossil fuels needed to run the island's desalination plant, the primary source of fresh water. Yet Aruba is actively pursuing a transition toward sustainability, as outlined in its Circular Economy Vision 2050 (Government of Aruba, 2019). Initiatives such as the Vader Piet wind farm, waste management innovations, and eco-tourism development reflect a commitment to reducing environmental impact while enhancing economic resilience (International Renewable Energy Agency (IRENA), 2020). The tokenization of carbon credits, enabled by blockchain technology, presents a unique opportunity to reinforce this transition by embedding carbon reduction efforts into the fabric of daily economic activities.

Through blockchain-based tokenization, Aruba could establish a localized carbon market where businesses, residents, and visitors actively participate in sustainability-driven economic exchanges. For example, hotels and resorts, key contributors to the island's carbon footprint, could purchase locally generated carbon credits to offset

their emissions, with transactions recorded transparently on a blockchain platform like the XRP Ledger (XRPL), known for its efficiency and low energy use (Ripple, 2022). Tourists could earn digital tokens by engaging in eco-friendly activities, like using renewable energy-powered transport or participating in beach cleanups, incentivizing sustainable behavior. The immutable nature of blockchain ensures the credibility of these offsets, allowing seamless verification by stakeholders, and reducing the risk of greenwashing, a big concern in carbon markets (Schneider et al., 2021).

Moreover, tokenized carbon credits could stimulate local enterprises to adopt sustainable practices by offering economic benefits for verified emissions reductions. Small businesses, such as restaurants or tour operators, could invest in energy-efficient technologies or waste reduction measures, earning carbon credit tokens tradable within Aruba or globally. By integrating blockchain-driven tokenization, Aruba could pioneer a model that not only supports its own sustainability goals but also serves as a blueprint for other SIDS navigating similar challenges. This approach aligns with the circular economy's emphasis on waste minimization and resource maximization, positioning sustainability as a cornerstone of Aruba's economic resilience.

2. Literature Review

Blockchain technology provides a decentralized, transparent, and secure framework for managing carbon emissions and facilitating carbon credit markets, addressing the inefficiencies of traditional systems. Two studies offer a technical foundation for exploring the potential of blockchain in monitoring emissions and tokenizing carbon credits in Small Island Developing States (SIDS). These highlight opportunities potentially enabling a system where emissions reductions are monitored, converted into tradable assets, and reinvested into sustainable initiatives. The first study examines a blockchain-based Digital Monitoring, Reporting, and Verification (D-MRV) system to enhance the accuracy and transparency of carbon emissions data, utilizing a consortium blockchain integrated with Internet of Things (IoT) devices by Frias (2025), who developed a distinct D-MRV framework inspired by Chen et al., 2024, and Effah et al., 2021. The second study by Guiterez et al. (2023) explores XRP Ledger (XRPL), a blockchain platform developed by Ripple Labs Inc. Ripple is a technology company focused on transforming global financial transactions through blockchain-based solutions. Founded in 2012 by Chris Larsen, Jed McCaleb, and others, Ripple developed the XRP Ledger (XRPL), an open-source, decentralized blockchain, and its native cryptocurrency, XRP. Unlike many cryptocurrencies that rely on energy-intensive mining (e.g., Bitcoin), the XRPL uses a consensus protocol involving validators to process transactions quickly (3-5 seconds) and at low cost, making it efficient and sustainable. Ripple's primary mission is to enhance cross-border payments for financial institutions, but it has expanded into tokenizing real-world assets (RWAs), such as carbon credits, to unlock liquidity and transparency in markets traditionally plagued by inefficiency (Ripple., 2025)

In the context of tokenizing real-world assets like carbon credits, Ripple leverages the XRPL's capabilities to represent tangible assets as digital tokens. Carbon credits, which certify the removal or reduction of CO2 emissions, are an emerging use case. Ripple's approach involves converting these credits into non-fungible tokens (NFTs) or other digital assets on the XRPL, enabling faster trading, transparent tracking, and reduced fraud. For instance, Ripple has committed $100 million to modernize carbon markets, partnering with organizations like CarbonCure Technologies and Xange.com to tokenize credits, ensuring their authenticity and scalability. This aligns with Ripple's goal of achieving carbon neutrality by 2030, using the XRPL's carbon-neutral design (achieved in 2020) to support climate solutions. By tokenizing carbon credits,

Ripple addresses issues like double-counting and opacity in carbon markets, making them more accessible and efficient for buyers and sellers, particularly in regions like Small Island Developing States (SIDS) where climate action is critical. for tokenizing carbon credits, drawing on Ripple's initiatives to scale carbon markets through partnerships and investments (Ripple., 2025)

2.1 Consortium Blockchain and D-MRV System Architecture

Frias et al. (2025) describes a Digital - MRV (Monitoring, Reporting and Verification) system that employs a consortium blockchain to monitor carbon emissions with precision and security, overcoming the limitations of manual MRV processes. A consortium blockchain, governed by multiple trusted stakeholders such as regulators and energy producers, balances decentralization with controlled access, making it suitable for collaborative environments in SIDS. Frias proposes a unique D-MRV framework inspired by the work of Chen et al.(2024), and Effah et al.(2021). Public blockchains like Bitcoin rely on energy-intensive proof-of-work (PoW), and private blockchains risk centralization; unlike these, consortium blockchains provide restricted participation, faster transaction processing, and lower energy demands, aligning with the resource constraints of SIDS (Frias, 2025).

The D-MRV system begins with a data acquisition layer, where CO2 sensors and energy meters are deployed at other locations which are used by the energy facilities to collect real-time emissions data. Ordinary nodes, typically energy producers who use CO2 sensors and energy meters that are installed at facilities (for example hotels or businesses) to collect emissions data, which they sign with a digital signature, timestamp and prepare for secure submission to the blockchain (Chen et al., 2024; Frias, 2025). In the validation layer, a secure method called the Elliptic Curve Digital Signature Algorithm (ECDSA) ensures the data's authenticity. Ordinary nodes add a digital signature to the data using their private keys, proving it's genuine (Johnson et al., 2001; Frias, 2025). To keep the data confidential, they encrypt it with the public keys of premium nodes such as regulators—so only these nodes can unlock it with their private keys for review. Premium nodes check the signatures with the ordinary nodes' public keys to confirm the data's source (Chen et al., 2024; Frias, 2025). A system called Delegated Proof of Stake (DPoS) helps validate the data efficiently, using trusted delegates instead of energy-heavy methods like Bitcoin's, which suits resource-limited settings (Karunakaran et al., 2021). The storage layer locks the validated data on the blockchain with a unique ID for tracking, ensuring it can't be altered. Finally, the data sharing layer uses smart contracts to control access, letting premium nodes see the full data while ordinary nodes only view basic details like timestamps, keeping sensitive information private (Chen et al., 2024; Frias, 2025). These smart contracts rely on the ECDSA-verified data to monitor emissions levels, automatically issuing warnings, penalties, or fines to energy producers if CO2 emissions exceed regulatory limits, ensuring compliance without delay.

Smart contracts in the D-MRV system can automate compliance by comparing emissions data against regulatory thresholds, potentially issuing carbon credits for reductions below limits or triggering penalties for exceedances, minimizing manual oversight (Bonini et al., 2023).

A smart contract is a self-executing program stored on a blockchain that automatically carries out actions when specific conditions are met, without needing intermediaries like lawyers or banks. Think of it as a digital agreement with built-in rules: once the terms are fulfilled, it runs itself, secured by the blockchain's transparent and unchangeable network. On the Ripple network, specifically the XRP Ledger (XRPL), a smart contract is a programmable feature or tool that automates tasks based on predefined conditions, leveraging the ledger's fast and efficient

design. The XRPL uses built-in functionalities like Escrow, Payment Channels, and the ability to issue custom tokens as smart contract-like mechanisms. These are pre-coded into the ledger and trigger automatically, offering speed (3-5 seconds per transaction), low cost, and simplicity, which suits Ripple's focus on real-time transactions and asset tokenization. For tokenizing carbon credits, an XRPL smart contract feature could hold credits in Escrow and release them to an energy producer once emissions data is verified and fullfils emission reduction goals, ensuring trust and efficiency with minimal energy use. This makes it ideal for managing real-world assets like carbon credits in systems like the D-MRV, especially in resource-constrained Small Island Developing States (SIDS). The D-MRV system demonstrates the potential for accurate and transparent emissions monitoring, which could serve as a foundation for carbon credit generation in SIDS like Aruba, where energy producers such as WEB Aruba N.V. might contribute to such systems (Chen et al., 2024; Frias, 2025). However, the literature does not yet explore how such a system could be integrated with tokenization platforms to create a fully functional carbon credit market in SIDS.

2.2 XRPL Framework for Carbon Credit Tokenization

The XRPL framework, developed by Ripple, provides a way to turn carbon credits into digital tokens, called non-fungible tokens (NFTs), making verified emissions reductions easy to trade as digital assets. Ripple is investing $100 million to grow carbon markets, working with climate-focused companies like Xange.com which is a Unetd Nations backed firm building a carbon credit solution on XRPL in order to make this happen (Guiterez, 2023). Unlike some blockchains that use energy-heavy processes, XRPL relies on a simple, efficient system with trusted validators to confirm transactions quickly and cheaply. This means it can handle lots of trades fast (thousands in seconds) at almost no cost, which makes it a practical choice for carbon credit trading (Guiterez, 2023).These attributes make XRPL a promising platform for a high-volume carbon credit market in SIDS.

In this context, carbon credits can be tokenized as NFTs, uniquely representing their origin, ownership, and retirement status to ensure traceability and prevent double-countingIn this setup, carbon credits become digital tokens called NFTs, each one unique to show where it came from, who owns it, and whether it's been used, making them easy to track and preventing reuse. The process is kept secure with a digital signature system, where energy producers sign the credits with a private code and others check them with a matching public code (Guiterez, 2023). Transactions are organized and checked efficiently to ensure everything adds up. Xange.com, for example, uses Ripple's XRPL to create these tokenized carbon credits from the African Great Green Wall Initiative, offering a simple web platform where energy producers can make and trade them, letting buyers like businesses or tourists purchase credits through digital wallets.

XRPL's performance surpasses alternatives like Ethereum, which, even after transitioning to Proof of Stake (PoS), achieves lower speeds (100–1000 transactions per second) and higher costs (approximately 1.30 USD per transaction). XRPL's carbon neutrality which is achieved through its consensus mechanism and Ripple's carbon offset initiatives, including pre-purchasing 120,000 carbon credits aligns with circular economy principles by minimizing resource use while scaling carbon credit markets in SIDS (Ripple, 2022).

2.3 Consensus Mechanisms and Security Primitives

Research from sources like Hu et al. (2020) and Ripple (2022) shows how smart systems and secure coding make carbon credit setups safe, fast, and trustworthy. For the D-MRV system, a method called Delegated Proof of Stake (DPoS) lets stakeholders pick trusted people to check emissions data quickly and with little energy, unlike slower,

power-hungry setups (Hu et al., 2020). It's fair because of voting, but could favor big players if cheating occurs where big players come together to hold a larger stake. Ripple's XRPL, however, uses trusted checkers to handle thousands of trades fast and cheap, skipping energy-heavy mining (Ripple, 2022). Both can deal with errors or trickery, keeping things solid (Nguyen et al., 2019).

Cryptographic Security comes from clever coding that locks and proves the data. In D-MRV, energy producers hide emissions info with a special key only regulators can open, keeping it private, and sign it with a secret code to prove it's real (Chen et al., 2024; Frias, 2025; Johnson et al., 2001). XRPL does the same for carbon credit tokens, signing them to show they're legit and adding extra checks to stop tampering (Guiterez, 2023). These tools such as hiding data with keys, signing it, and double-checking are the backbone of the system to make sure emissions tracking and credit trading are secure and clear, building trust for a carbon market in Small Island Developing States (SIDS).

2.4 Case Studies of Blockchain Application from Other Small Island Developing States

To contextualize the potential adoption of blockchain-based carbon credit systems in SIDS like Aruba, it is valuable to examine efforts in other Small Island Developing States that are exploring or implementing digital climate finance tools. While few have fully operationalized blockchain-integrated carbon markets, several have laid foundational groundwork that could complement and support the frameworks proposed by Frias (2025) and Guiterez (2023). These include Fiji, the Seychelles, the Maldives and Barbados, each of which has dimensions with potential relevance for applications in Aruba.

Fiji's blockchain pilot for climate resilience financing was launched around 2020 with the UN Development Programme (UNDP) and the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE). It aimed to track funds earmarked for adaptation projects in remote Pacific communities. The initiative deployed a blockchain ledger to record disbursements as digital tokens, using mobile phones for community members to input project data (for example microgrid installations) via SMS or basic apps, syncing to the chain through local hubs despite limited internet access (UNDP, 2020 & PCREEE, 2020). This reduced fund leakage, ensuring funds reached intended recipients, as even in remote villages, they could prove expenditures transparently, enhancing trust and accountability.

While Fiji's pilot was not emissions-focused, it aligns with Frias's (2025) D-MRV emphasis on verifiable, real-time data collection, and suggests the viability of a low-tech entry point for tracking tourism emissions via mobile apps. Combined with XRPL's (Guiterez, 2023) efficient tokenization capabilities, an implementation inspired by Fiji's model could allow Aruba to upstream its carbon market with transparent financing, supporting infrastructure like IoT deployment for D-MRV (Frias, 2025), reinforcing its Circular Economy Vision 2050 (Government of Aruba, 2019)

In 2022, Seychelles pioneered the world's first Blue Carbon NFT pilot with Oceanium and Envision Blockchain, tokenizing carbon sequestered by mangroves to fund conservation, blending ecological restoration with digital markets. Field surveys and possibly remote sensing measured sequestration, with data verified and minted as NFTs on a blockchain, each representing carbon tonnage offset sold to corporations or donors(Envision Blockchain, 2022 & Oceanium, 2022). The pilot successfully raised funds for mangrove restoration and gained global notice for proving SIDS could monetize natural capital.

The initiative in Seychelles focuses on investment in ecosystems, rather than offsetting industrial emissions (as in Frias 2025), but its NFT approach is comparable to XRPL's

tokenization capabilities (Guiterez, 2023), leveraging low-cost, traceable transactions. In Aruba, expanding D-MRV to coastal assets and tokenizing restoration credits alongside tourism offsets on XRPL could enhance its circular economy by integrating natural and economic value (Government of Aruba, 2019).

The Maldives, a tourism-dependent SIDS, began exploring Digital Monitoring, Reporting, and Verification (D-MRV) systems in 2023 with its Ministry of Environment and Maldives Tourism Authority, partnering with tech firms to track resort and transport emissions for voluntary tourist offsets, though it remains in feasibility stages. The plan integrates IoT sensors (for example, on boats and generators) with a blockchain to log real-time emissions, potentially tokenizing credits via a platform like XRPL, with tourists purchasing offsets through resort apps or dashboards (Ministry of Environment, Maldives, 2023 & Maldives Tourism Authority, 2023). Still in planning, it aims to turn 1.5 million annual visitors carbon footprints into sustainability revenue for funds that could be funneled to initiatives for reef protection, mirroring Frias's (2025) D-MRV vision for precise monitoring.

The initiative in the Maldives parallels the tourism context of Aruba (UNWTO, 2021), suggesting that a D-MRV (Frias, 2025) and XRPL (Guiterez, 2023) system could operationalize offsets faster, linking hotel emissions to visitor engagement, advancing its Circular Economy Vision 2050 (Government of Aruba, 2019) where Maldives lags.

Barbados, partnering with fintech startup Bitt in 2021, utilized blockchain to issue green bonds for climate resilience projects like water systems or renewables, focusing on financing rather than carbon credits. The bonds were issued on a private blockchain, enabling investors to buy digitally while tracking funds transparently from sale to project execution, cutting out intermediaries (Bitt, 2021 & Government of Barbados, 2021). This streamlined funding, outpacing traditional bonds, and established a Caribbean regulatory model, supporting resilience efforts without direct emissions tracking.

While distinct from Frias's (2025) D-MRV emissions focus, Barbados's initiative shares XRPL's (Guiterez, 2023) efficiency concepts, offering Aruba lessons in structuring markets. Barbados's public-private success suggests Aruba could issue bonds to fund D-MRV infrastructure or XRPL integration, ensuring legal clarity and stakeholder buy-in for a circular carbon economy aligned with its 2050 vision (Government of Aruba, 2019).

3. Discussion

3.1 Methodology for Implementation in SIDS: Aruba as a Pilot

Implementing a blockchain-based carbon credit system integrating Frias's (2025) D-MRV with XRPL tokenization (Guiterez, 2023) offers a scalable framework for Small Island Developing States (SIDS), with Aruba serving as a pilot to refine and demonstrate its potential. This methodology outlines a step-by-step plan leveraging tourism economies, local governance, and regional collaboration to address the resource constraints and climate vulnerabilities common across SIDS (UNFCCC, 2021). Anchored in Aruba's Circular Economy Vision 2050 (Government of Aruba, 2019), it provides a short flexible exploratory blueprint adaptable to other SIDS contexts.

The first step involves deploying IoT devices like CO2 sensors and energy meters at major emission sources, such as Aruba's WEB Aruba N.V. and hotels who are key contributors to tourism-related emissions (UNWTO, 2021). These devices, managed by local businesses acting as nodes, capture emissions data in real-time, with solar-powered sensors addressing power disruptions which is common in SIDS (IRENA, 2020). Training programs, supported by

regional bodies like IRENA or PCREEE (PCREEE, 2020), equip local technicians, enhancing the technical capacity of SIDS like it did for Fiji & Barbados.

The second step establishes a collaborative consortium blockchain, involving government bodies, private sector players, and regional SIDS partners, following the framework of Frias (2025). The use of Delegated Proof of Stake (DPoS) consensus, with elected delegates like regulators, ensures efficient data validation while minimizing energy use, crucial for SIDS limited grids (Karunakaran et al., 2021). Smart contracts automate credit issuance based on emissions benchmarks (Bonini et al., 2023), allowing seamless tokenization and the potential to create a Caribbean coalition, sharing expertise across SIDS.

The third step integrates validated carbon credits into XRPL, tokenizing them as NFTs such as "AruCarbon" for Aruba. A web-based platform, developed locally or with partners like Xange.com, enables minting and trading which leverages XRPL's low-cost, high-speed transactions, providing wallet access for tourists, businesses, and potential regional buyers. This positions Aruba to engage with global carbon markets, with Aruba testing scalability.

The final step involves initiating a pilot phase in Aruba, starting with select participants such as hotels and WEB Aruba N.V., before expanding island-wide and regionally. Incentives, including tax reductions and accessible IoT kits could encourage small business participation, while workshops and awareness campaigns funded by tourism levies drive stakeholder buy-in. Proceeds from token sales would be reinvested into renewable energy projects or waste management, further amplifying sustainability efforts. Regional collaboration with other SIDS like Seychelles (Envision Blockchain, 2022) would help standardize the approach, strengthening climate finance and resilience across vulnerable island nations.

3.2 Technical Challenges and Research Opportunities

The literature identifies several technical challenges in applying these frameworks to SIDS carbon markets, which present opportunities for future research. The D-MRV system's reliance on IoT devices and cryptographic overhead may strain infrastructure in resource-limited settings like Aruba, suggesting a need for lightweight algorithms or cost-effective deployment strategies (Chen et al., 2024; Frias, 2025). DPoS risks centralization if delegates collude, while XRPL's validator network requires trust and coordination that should be developed through policy making in SIDS. These challenges highlight the need for future research to optimize cryptographic processes, test integrated pilots in SIDS like Aruba, and develop governance models to ensure equitable participation. Such studies could refine the potential of these frameworks, providing a clearer path for implementing carbon credit markets in SIDS that support circular economy principles.

3.3 Potential Integration of D-MRV and XRPL for Carbon Credit Tokenization Across SIDS

The literature reviewed suggests that combining a D-MRV system with XRPL tokenization could create a strong carbon credit market for Small Island Developing States (SIDS), with Aruba as a promising example. Frias et al. (2025) show that the D-MRV system can track emissions in real-time, ideal for Aruba's goal of transparent monitoring under its Circular Economy Vision 2050 (Government of Aruba, 2019). For Aruba, this could mean placing IoT devices at facilities like WEB Aruba N.V. to gather emissions data, stored securely on a consortium blockchain. Smart contracts could then reward verified low emissions with carbon credits, tailored to Aruba's energy sector (Chen et al., 2024; Frias, 2025). Ripple's XRPL could turn these credits into tradable digital tokens (NFTs), using its fast, low-cost system to boost Aruba's carbon market and attract buyers

like tourists or businesses (Guiterez, 2023). For instance, a hotel in Aruba reducing emissions through energy-efficient practices might earn credits that are tokenized as "AruCarbon" NFTs, which could be traded to tourists or businesses via a web application integrated with XRPL wallets, with proceeds potentially funding sustainable projects like solar installations or waste-to-energy plants.

Combining the D-MRV system with Ripple's XRPL could blend their strengths for a better carbon credit system in Small Island Developing States (SIDS). The D-MRV's group-managed blockchain keeps emissions data honest and secure using trusted checkers and special coding, while XRPL's fast, low-energy setup turns credits into digital tokens (NFTs) for easy trading. Smart contracts which are automatic digital agreements could be able to connect the two systems, handing out credits in D-MRV and sending them as NFTs on XRPL, cutting out middlemen and speeding things up. In Aruba, this could support a circular economy by using money from NFT sales to fund green projects, like cleaner energy or less waste, fitting its sustainability goals. While this mix of D-MRV and XRPL looks promising, it hasn't been tried in SIDS yet, leaving questions for future studies to answer.

The D-MRV and XRPL frameworks could collectively offer a technical benchmark for carbon credit tokenization in Aruba, addressing key challenges in emissions monitoring and market creation. The D-MRV system's multi-layered architecture ensures that emissions data is accurate, tamper-proof, and verifiable, a prerequisite for credible carbon credits. XRPL's high throughput and low-cost transactions could enable a vibrant market, making carbon credits accessible to diverse stakeholders, from local businesses to international investors. The use of NFTs ensures traceability, preventing fraud and double-counting, while XRPL's carbon neutrality aligns with circular economy goals by minimizing the environmental footprint of blockchain operations (Ripple, 2022).

In Aruba, implementation of this benchmark could support a circular economy by creating a cycle where emissions reductions are monitored, tokenized, and traded, with proceeds reinvested into green initiatives, reducing waste and enhancing sustainability. The frameworks' reliance on ECDSA, smart contracts, and efficient consensus mechanisms suggests security and scalability, making them potentially adaptable to other SIDS with similar resource constraints and sustainability goals.

4. Conclusion

This paper illustrates how integrating Frias's (2025) D-MRV framework with XRPL tokenization (Guiterez, 2023) could redefine carbon management across Small Island Developing States (SIDS), using Aruba as a pioneering example to advance its Circular Economy Vision 2050 (Government of Aruba, 2019). By deploying IoT and blockchain for emissions monitoring (Frias, 2025, inspired by Chen et al., 2024, and Effah et al., 2021) and tokenizing carbon credits on XRPL, Aruba transforms its tourism-driven emissions into a resource, reducing waste and diversifying revenue streams amid import and visitor dependency (UNWTO, 2021). This not only strengthens local resilience but positions SIDS as active players in global climate solutions.

Beyond Aruba, this model addresses systemic SIDS exclusion from carbon markets (World Bank, 2022), offering a blueprint rooted in blockchain's accessibility and efficiency. Its potential spans the Caribbean and Pacific like that of Seychelles could scale its Blue Carbon NFTs (Envision Blockchain, 2022), Maldives could operationalize tourism offsets (Ministry of Environment, Maldives, 2023), and Barbados could fund it via green bonds (Bitt, 2021). Collectively, this could amplify SIDS contribution to Paris Agreement goals (UNFCCC, 2021), turning vulnerability into a unified strength. Yet, success demands rigorous testing. Pilot programs must assess infrastructure limits,

cultural adoption, and economic viability, while policies must balance equity between large and small stakeholders . Future research should prioritize multi-SIDS trials to further go about Aruba's IoT deployment and token uptake could inform a regional framework, refined through comparisons with Fiji's financing model (UNDP, 2020) or Seychelles' ecological approach. Such studies could solidify blockchain as a cornerstone of SIDS resilience, linking local action to global markets. By leading this charge, Aruba not only secures its sustainability but elevates SIDS as innovators, harnessing technology to shift from climate victims to climate leaders, with ripple effects for small economies worldwide

References

- Banking Innovation through Technology. (2021). Barbados explores blockchain for green bond issuance and digital payments. Bitt. Retrieved April 9, 2025, from https://www.bitt.com/
- Chen, M., & Hsiao, H. (2024). Blockchain for environmental monitoring in SIDS: A comprehensive framework. Journal of Sustainable Technology, 12(3), 112-130.
- Chen, Z., Liu, Y., Wang, E., You, H., Gao, Q. G., F. D., & Li, J. (2024). Advancing the deployment and information management of direct air capture: A solution enabled by integrating consortium blockchain system. Carbon Capture Science & Technology, 13, 100112. https://doi.org/10.1016/j.ccst.2024.100300
- Envision Blockchain. (2022). Seychelles launches blue carbon NFT pilot for climate change mitigation. Envision Blockchain. Retrieved April 9, 2025, from https://www.envisionblockchain.com/
- Ellen MacArthur Foundation. (2015). Towards the circular economy: Economic and business rationale for an accelerated transition. Retrieved April 9, 2025, from https://www.ellenmacarthurfoundation.org
- Frias, J. (2025). Blockchain-based carbon credit systems for Small Island Developing States: A case study of Aruba. Retrieved April 9, 2025, from https://docs.google.com/document/d/1rl6QgF_49pCFsFE_0IAiwV2wCAzaWJOdPIUiWs4v31U/edit?tab=t.0
- Government of Aruba. (2019). Circular economy vision 2050. Retrieved April 9, 2025, from https://www.government.aw
- Government of Barbados. (2021). Blockchain-based green bonds to finance climate resilience. Retrieved April 9, 2025, from https://www.gov.bb/
- Guiterez, M. (2023). Tokenizing college courses using the XRPL. Retrieved April 9, 2025, from https://content.manhattan.edu/reference/thesesOA/gutierrez2023.pdf
- Hu, Z., Du, Y., Rao, C., & Goh, M. (2020). Delegated

proof of reputation consensus mechanism for blockchain-enabled distributed carbon emission trading system. IEEE Access, 8, 214932–214944. https://doi.org/10.1109/access.2020.3041689

- International Renewable Energy Agency. (2020). Renewable energy roadmap for Aruba. Retrieved April 9, 2025, from https://www.irena.org
- Johnson, D., Menezes, A., & Vanstone, S. (2001). The elliptic curve digital signature algorithm (ECDSA). International Journal of Information Security, 1(1), 36–63. https://doi.org/10.1007/s102070100002
- Karunakaran, C., Ganesh, K., Ansar, S., & Subramani, R. (2021). A privacy-preserving framework for health records using blockchain. Pertanika Journal of Science and Technology, 29(4), 2725–2746. https://doi.org/10.47836/pjst.29.4.45
- KlimaDAO. (2023). Annual report: Decentralized carbon markets. Retrieved April 9, 2025, from https://www.klimadao.finance
- Ministry of Environment, Maldives. (2023). Exploring digital MRV systems for tourism emissions tracking and offsetting. Retrieved April 9, 2025, from http://www.environment.gov.mv/
- Maldives Tourism Authority. (2023). Feasibility study on integrating blockchain and IoT for emissions tracking. Retrieved April 9, 2025, from http://www.tourism.gov.mv/
- Narayanan, A., Bonneau, J., Felten, E., Miller, A., & Goldfeder, S. (2016). Bitcoin and cryptocurrency technologies. Princeton University Press.https://press.princeton.edu/books/hardcover/9780691171692/bitcoin-and-cryptocurrency-technologies?srsltid=AfmBOopIDJ-a1R_6iWyuJbI5rzTT86nfSdAZthaxTTodFkSksMboLWBl

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Hoiii, can I ask you something?

'Hoiii, can I ask you something?' became a familiar prompt the past months. Few people in my circle could escape that question when I needed clarity for my thesis, but also few Aruban students hanging out alone on the university campus.

This field research program experience surpassed all my expectations and hopes in ways I never imagined. While Eric tried hard with his well-known 'depression tour', which consisted of various locations illustrative of the sustainability challenges on the island, I did manage to feel hopeful again. The primary reason for this was the great amount of inspiring, caring, and hardworking individuals I had the privilege of meeting. They not only showed the possibilities for change on the island but also shared their ambitious, supportive, and hopeful energy with us. Therefore, the past months felt incredibly uplifting. Following the majors history and politics on University College Utrecht educated me on the realities of the world, consisting of a considerable amount of real problems. This resulted in me sometimes feeling dispirited about being able to 'change the world'. However, thanks to all these spirited people I met during this program, I gained back a sense of optimism. As multiple people in different variations told me 'we don't have to save the whole world today, we can simply begin today, and here on this island. Starting and trying to finish something no matter how long it takes, is enough.' This perspective made the challenges we explored during our research projects, as well as Erics tour, more understandable and accessible.

The longer we stayed, the more possibilities we came across. Andicuri beach, visited before, suddenly revealed a stunning hidden cave. Forgetting all my daily worries -concerns about my thesis, my lack of basic health insurance, and even the question of 'what is our next meal going to be'-thanks to having to follow Zaza in explorer mode. A road we passed

repeatedly, suddenly housed a spot with delicious pastechi and smoothies. Going kiting until right before sunset and watching it from the top of the Hooiberg on the same day, is in fact possible, if you just run up in six and a half minutes. Going for a run through the streets became possible if you just run quickly enough to keep the stray dogs at bay.

The interviews I conducted provided invaluable insights into people's experiences, which were fascinating and important not only for my thesis. They illuminated how much uplifting energy people feel for a community .This was my first time conducting field research with 'real people,' which made the experience invaluable. Although I felt increasingly nervous before each interview, I began to find joy in the process.

Sharing this journey with a new group of people was everything I could have hoped for and more. Each person brought something unique to our collective experience, and living together while discussing our projects proved to be immensely valuable. I am grateful to everyone we met for opening up and allowing us a glimpse into their lives and community. Furthermore, I wanna thank my fellow classmates for being kind, patient, and inviting, offering help to us not only with our research but also for exploring the island as well.

Thank you, Jocelyn and Eric, for providing inspiration, flexibility, and openness to ideas while listening to my desperate rants and reminding me that solutions always exist, and everything will be okay. To my fellow students, you offered invaluable academic guidance, patience during my moments of feeling insane, kept me fuelled with the prospect of pasta, and lifted my spirits with spontaneous dance breaks. I look forward to being able to look back on this experience, while living back in Utrecht, with the people I am thankful for now being able to call my friends. While it was hard not to develop feelings for Aruba, I also got to experience what a privilege it was to have the feeling of missing my friends and family back home.

What's Missing? Exploring Aruban Students' Perspectives on their High School History Education

Lisa Ravenhorst

Introduction

'This one is for you and me, this one is for unity', a sentence from the song *1 for Unity*, by Soca Monarch Winner 2025, Freddy Rasta, captures a vision of Aruban unity (Rasta & the Gang, 2025). However, a more complicated picture emerges underlying this vision of Aruban unity: one of slavery, colonization and decolonization, a continued asymmetrical relationship with The Netherlands, and one of people coming from many heritages speaking a range of languages. Moreover, although Aruba is a small island in the Caribbean, it is deeply connected with the Caribbean region through migration, the Global North through tourism, and the rest of the world through the many Arubans living in diaspora. All these histories influence and complicate the nation building processes in Aruba.

Despite many Arubans having many different origins, Aruban children have a certain shared experience: their education. Education curricula - and in particular the history curriculum - have long been deemed a vital factor in the process of nation-building. But the what and how of histories that are taught may vary, and may betray something about the state Aruba wants to be. As it is impossible to teach everything and a neutral approach does not exist, conscious choses need to be made when developing a curriculum (Barton & Levstik, 2004). This paper will not examine the Aruban history curriculum in depth, instead centering the experiences of Aruban students with …. This community-engaged approach is bottom-up , fitting in a pluralistic postcolonial research agenda which amplifies voices from those who are not always heard in education discussions..

First, the paper briefly provides a history of Aruba, the development of the education system and the history curriculum. Secondly, the paper sketches a theoretical framework of the links between nation building, identity formation, postcolonialism and history education. The paper then proceeds to the heart of the research. The author interviewed Aruban students and asked the interviewees on history education in high school, and more specifically on Aruban history, on Spanish and Dutch colonization, on the relationship between local, regional, and international content, on biases in presentation of the materials, cultural identity and the future of history education. The results provide novel albeit limited insights into students' perception of their history education. The methodology of these semi-structured interviews will first be described, and then the coded, preliminary findings will be presented. In the conclusion section, the author links back the findings to the broader theoretical framework of national identity, postcolonialism and history education to answer the research question:

To what extent do the perceptions of Aruban high school graduates regarding their history education reflect

challenges of nation-building in a post-colonial context?

Existing Research and theoretical framework

Historical and Geographic context

Aruba, Bonaire and Curaçao form the ABC-islands, also called the Dutch Leeward Islands. These islands, together with Sint Maarten, Sint Eustatius and Saba, form the Dutch Antilles: The Caribbean part of the Kingdom of the Netherlands. The Netherlands colonized these six islands since 1636, following up the Spanish colonization (Hartog, 1961). Formally, this colonization ended in 1954, as the Antilles gained domestic autonomy. On the first of January, 1986, this changed further, as Aruba acquired a status aparte, constituting separation from the Antilles and functioning as an autonomous country within the Kingdom, with a Gouverneur as part of the political body. Nevertheless, as a constituent nation, Aruba is not completely separate from the Dutch sphere of influence.

The historical background of Aruba developing as a multicultural society throughout the decades is connected to the contemporary level of diversity of the Aruban population. An overview published by the Central Bureau of Statistics shows that in 2022, the island of Aruba is composed of 64.4% of the population being born in Aruba or the former Netherlands of Antilles, 9,7% was born in Colombia, 5,4% in Venezuela, 4,6% in the Dominican republic and 4,5%, leaving 11% of the population to be born in a wide variety of different countries (The Central Bureau of Statistics and the Civil Registry and Population Office, 2022). With this cultural diversity also comes complexity (Hickling-Hudson, 2007).

This complex cultural diversity is shaped by historical processes such as migration, remigration, state-building and nation-building in the past decades (Allen, 2021; Alofs, 2003). Beyond being a part of the Dutch Kingdom, Aruba is characterized by Latin-American and Caribbean features, coming together and creating a unique position. Alofs (2003) describes the history of developments of research on Aruban Cultural Heritage from 1987 onwards, demonstrating that the search for a distinct Aruban identity went hand in hand with the intensifying desire for reaching the Status Aparte. However, Alofs concludes this overview by pointing out that scientific research on Aruban cultural identity remains to be insufficient, especially with the Aruban community consistently rapidly changing. Therefore, the wide diversity in Aruban cultural heritage isa dynamic process, rather than a constant concept, which can be seen as a given. Furthermore, it remains to be investigated if shared heritage on the islands exists at all, and to what extent there is a shared cultural and national identity. With a past involving intense migration and international influences, Aruban culture is inescapably involved with other cultures, creating a heterogenous, hybrid culture (Said, 1994).

Self-perception of Arubans through cultural heritage has been researched. While Aruba has a history of slavery, Aruba perceives itself as a Mestizo nation that hardly has one (Allen et al,, 2023; Oostindie & Klinkers, 2010). In Aruban museums Afro-Caribbean and Asian histories are represented superficially (Stipriaan et al., 2023), instead centering Indigenous legacies a. What effect does this have on their cultural heritage/day to day lives?

Nation-building

Nation-building can be defined as the idea of a common "we" within a country (Allen et al., 2023). It has been questioned if Aruba, and the other Dutch Caribbean nations for that matter, are nations at all, since they lack strong independent institutions, economic power, cohesion and the will to transcend from being a nation to being a sovereign state (Ferdinand et al., 2020; (Oostindie, 2005)).

Traditionally, mainstream academics define a nation in a constructive way, as 'an imagined political community - and imagined as both inherently limited and sovereign' (Stipriaan et al., 2023). Nation-building, then, is the internal cohesion of a nation through social processes and aimed at creating an exclusive "we" (Stipriaan et al., 2023). Nation-building takes place across multiple dimensions and can be economic, sociopolitical or sociocultural. Nation-building can be both top-down and bottom-up. Nation-building also entails the process of making citizens feel a commonality of interests, goals and preferences so that they do not seek secession and separation (Alesina et al., 2021).

The complexity of Aruban national identity has been mentioned earlier, and for the last decades questions have been asked about who is Aruban and who is not, or what it means to be 'Aruban'. In 2001, Alofs and Merkies showed the politics and narratives surrounding the question 'Ken ta Arubiano?'. This discussion is described by Artwell Cain in 'Sense of Belonging' via the narratives of 39 Arubans articulating their narrative regarding identification of being Aruban (Cain, 2017). These narratives show a wide range in answers and classifications on 'who or what is Aruban', . Guadeloupe (2009) argues that there is a sense of awareness in the Caribbean because of the constant flow of migrants throughout history, creating a form of samenesswhere everyone has a history from a different place and was a newcomer at one point.

Arubans had to seek a sense of belonging following the autonomous status, which fell outside of many conventional processes (Pijl & Guadeloupe, 2015). For Aruba, it wasnot possible to create a binary 'Us' and 'Them' narrative in their nation building. For the inhabitants of Aruba, belonging is not limited to Aruba, as there is also a sense of belonging within the Dutch Kingdom (Guadeloupe 2009). Creating a sense of supra-national identification and importance continues to be a struggle, not only in Aruba, but also in the European part of the Kingdom (Alofs 2011). To create a sense of pluri-identification, the unique context of Aruba and the Kingdom calls for flexibility, as it is shaped by factors beyond the physical boundaries of the island.

This debate on Aruba's identity intersects with the discussion of nationalism. The emergence of ethnic movements, such as the Aruban one, fit within the argument presented by Eriksen (2002). Eriksen (2002) argues that there is not a 'natural' formation of a national or ethnic identity. Instead, these are actively constructed (Eriksen, 2002). In debates on conflicting identities within a country, nation-building can function as an important tool in bringing a country together. In turn, the foundation and sustaining of the Aruban nationality are rooted in history. As history has both the possibility to foster national identity of a state, but also deepen persisting shattered social cohesion, it is important to acknowledge the role of history education, as this is an accessible, impactful, source (Sandhu et al., 2023).

In the literature it is widely accepted that history education plays a central role in nation-building (Alesina et al., 2021; Durand & Kaempf, 2014; Durrani et al., 2020). History education deals with political and national history, and has often been found to contain certain 'Master Narratives', aimed at instilling patriotism, cultural heritage, and yes, national identity (Zajda, 2015). In that sense, history allows for an imagination of the nation which leads to identity formation (Faden, 2015). Accounts of history help create an understanding of who we are, where we have come from, and in what direction we should be heading (Liu & Hilton, 2005).

Education system

The education system of Aruba remains to be defined by the Dutch colonization, starting with the Dutch language. As of 1819, Dutch has been the official and only language in Aruban schools, aiming to eliminate Papiamento (Stipriaan et al. 2023). The Dutch colonizers imposed multiple policies

to eradicate Papiamento, which was spoken in everyday life, and promote the Dutch language instead. Examples include requiring schools to teach in Dutch in order to receive subsidies and imposing licensing requirements on teachers (Pereira & Alofs, 2023). Despite these colonial policies, Papiamento became the official language of Aruba in 2003 (Pereira & Alofs, 2023). Since 2002 Papiamento has been introduced as a subject in the education curriculum, but the official teaching language of high schools remains Dutch. The discussions around the primary language in the Aruban education system has a long history. In the late 1960s, after the autonomy of Aruba in 1954, the first debates were sparked on whether Arubans should receive an education in their native language(Pereira & Alofs, 2023). While teaching experts agree that it is better to receive education in the native language, counter-arguments include that the community is not ready for Papiamento, there are no teaching materials available, and that it is not possible to learn using Papiamento. These arguments all betray a neo-colonial attitude and precisely underline the problematic colonial heritage of Aruba. Since 2018, the Scol Multilingual model has been rolled out in Aruban primary schools but not in the high schools (Overheid van Aruba, 2023)..

The school system of Aruba is based on the school system of the Netherlands. First, children can follow pre-school education, from age 4 to 6. This is followed by primary school for children between 6 and 12. When reaching the last year of primary education, students continue to secondary education, with the level being based on a combination of their marks, the primary school's recommendation and in some cases a test (Departamento Di Enseñansa Aruba, n.d.). Subsequently students go to either a public school or private school for secondary education. Public schools are divided into vocational EPB schools (Diploma Education Profesional Basico) and EPI, MAVO schools (Middelbaar Algemeen Voortgezet Onderwijs) and HAVO and VWO schools (Hoger Algemeen Voortgezet Onderwijs/ Diploma Voorbereidend Wetenschappelijk Onderwijs). In addition there is also special secondary education, SPO. The two private schools are De Schakel, which offers a Dutch oriented high school diploma and the International School of Aruba (ISA), which allows for an American High School Diploma (Nuffic, n.d.; Departamento Di Enseñansa Aruba, n.d.).

Existing research on education on Aruba has focused on the role of Dutch as the official language of education, since Dutch is almost no student's first language (Hüning & De Wilde, 2022). Other education research has centred around dimensions of cultural heritage, such as archaeology, art, sports and literature (Stipriaan et al., 2023). The role of history as a part of cultural heritage remains under-researched. A report published by UNICEF (2013), in which they assessed the island's education system and gave recommendations, pointing out the issue of education content being too orientated on the Netherlands. Instead, UNICEF (2013) sees the need for the development of a new program, which would have to be adapted to the needs of a culturally diverse society, such as the one in Aruba. This is similar to Lévesque's (2017) assertion on different groups in society identifying with and searching for different aspects of the past.

The learning objectives in Aruban secondary schools are important to understand …. The Ministry of Education of Aruba sets the learning objectives (eindtermen) for Aruban secondary schools. During the years 2007-2017, Aruba followed the Nationaal Onderwijs Plan (NOP), which is followed up by the Plan Educacion Nacional 2030 (Coördinatieteam Nationaal Onderwijsplan 2030 & Directie Onderwijs Aruba., 2019; The Learner: Our Focus, A Strategic National Education Plan 2007-2017, 2007). Central in the revising of the second plan, was to integrate Aruban identity more in education. The Directie Onderwijs Aruba, illustrates in this plan their goal to combine 'het Arubaanse eigene', which is being linked to language and culture, with the broader context of contemporary global developments. The current problem in education is that it

is based on an outdated set of norms and values, with a lack of the 'authentic and Aruban identity' (Coördinatieteam Nationaal Onderwijsplan 2030 & Directie Onderwijs Aruba, 2019, p.25). The official document acknowledges the importance of history and context, and that it is important the course meets the world of the Aruban student. History education should prepare the Aruban student for life as a citizen of Aruba, but also as a citizen of the world. The word 'Aruba' is featured heavily with 31 hits. Former colonizer 'The Netherlands' only features three times. This fits within the conclusion made by Oostindië(1992): the process of decolonization must be seen as an ongoing process (Eindtermen En Examenprogramma Voortgezet Onderwijs Aruba, 2024).

Postcoloniality and education

Specific challenges arise in the educational context of postcolonial states like Aruba. According to Boiselle (2016), postcolonialism is necessarily anticolonial and anti-imperialistic and is seeking to deconstruct historic movements of subjugation in all dimensions. In the context of history education, tensions and opportunities arise, such as 'history wars', but also the possibility of de-colonising the mind (Brett & Guyver, 2021;Taylor & Guyver, 2014). As Hickling-Hudson (2004) explains, efforts have been made in changing neocolonial Caribbean education systems, breaking down traditions in education inherited from former colonizers. Moreover, she argues that colonised ways of thinking can be avoided, in the context of exploring this relation between education and cultural complexity, by adopting a postcolonial framework (Hickling-Hudson, 2007). Including local histories and cultures within the education framework is essential. Education needs to align with the needs and identities of Caribbean people (Hickling-Hudson, 2004).

An often identified link between the relevance of teaching historical skills and understanding to young people, is that it can facilitate student participation in the democratic society (Barton & Levstik, 2004; Lévesque, 2008). A historical understanding can deconstruct monolithic thinking and objectives, as well as narratives of the 'other'. History can provide consistent and regularities, in a society, which is inherent to disagreement and debate. According to Homi Bhabba (Bhabha, 2013), each nation has its own crafted narrative. Wynter (2003) creates an argument on the coloniality of this knowledge. Dominant narratives which are created from a Western-centric perspective often obscure the experiences of marginalized groups. Moreover, research and debates on history are not limited to just history in itself, it relates to the history curriculum. Brett and Guyver (2021) argue that especially in the context of postcolonial states reframing their national identities, history education can provide new methods of identity construction. As postcolonial emerging states reframe and re-articulate their national identities, history education must provide new methods of thinking and doing that respect the unique histories, contexts, and realities of these states.

Scholars are also optimistic about the opportunity to build bridges, create more inclusive history curricula, complicate homogeneous national narratives and listen to the student voice.

Methodological Overview

Method of Data Collection

The methodology used for this paper was community-based research, consisting of qualitative semi-structured interviews with students on their high school history education. The paper is part of a more extensive bachelor research paper, which will also embed qualitative insights from the community within the wider body of academic literature. A literature review was first conducted in order to gain an understanding of the historic and educational

context of Aruba. Next to this, to gather insights into students' perceptions of their history education, semi-structured interviews were conducted. For this paper the first set of interviews, consisting of ten participants, was used as the data set, from which preliminary findings follow. The method of using semi structured-interviews was chosen because it offers flexibility in questioning, in order to explore students' reflections whilst maintaining a certain focus on initial themes of the research. These themes flowed forth from the literature review. The next step entailed the creation of thematically organised selected sets of questions, from which questions were chosen during the interview depending on the answers of the participant. Therefore, the interviews were designed to cover reflections on historical significance, the role of Aruban national history, the balance between local, regional and international history, the relationship with cultural identity and future suggestions. The order of questions varied as they followed the flow of the conversation, but all interviewees were asked at the end of the interview about possible suggestions they had for future history education reforms. This was exploratory research and a case study: the results are not intended to be generalised outside of the context.

Measurement Instrument

In the conversations, open-ended questions were asked to allow students to freely reflect on their education. Points of focus were the topics they remembered, the emphasis that was placed on these topics and on any identified controversies and gaps. In addition, questions about the participant's age and school history were included. The formulations of the questions were based on similar studies, exploring students' perceptions (Morgan, 2023). This qualitative research strategy involved gathering information on facts and representations found during oral exchanges. Semi-structured interviews have certain benefits. For instance, the purpose was to flexibly find out respondents' perspectives in respect to a predetermined research goal (Bryman 2012). Semi-structured interviews provide a social connection to encourage direct communication with a second party who serves as both the researcher's subject of study and responder (Alles et al., 2016).

Participants

The interviews were conducted on the campus of the University of Aruba in the period of….. Participants consisted of students with an age range of 18 to 28, who were approached on campus and introduced to the study, after stating their willingness to participate in the study. Therefore, this research is convenience sampling based, utilizing a research population that was available and accessible. This method is effective when conducting an explorative study which plans to obtain insights into people's perceptions (Golzar et al., 2022). The interviews were audio-recorded, consent was requested orally and participants were informed about voluntariness of their participation. Due to the limited linguistic background of the researcher, interviews were conducted in either Dutch or English. Transcription and translation of the recordings to English transcripts was done by utilizing the website TurboScribe (2023). During the transcription phase, data was anonymized, and names were replaced by the chronological number of the interview. The participants include both University students and students from the AFY Program. This is a pre-university program of one year and aims to fully prepare students for higher education (Chapman et al., 2024). Since the participants graduated from high school in different years, and followed different levels in high school, their answers do not reflect a single high school curriculum.

Thematic analysis

The descriptive data provided by these conversations allow for a thematic analysis that looks for patterns or recurring topics across participants (Naeem et al., 2023). Thematic

analysis will be used to identify and interpret the findings in relation to the literature. This approach of on one hand giving a voice to the individuals, on the other hand does come with acknowledging that this approach involves making decisions in terms of which information is selected in order to create an argument (Fine, 1992). This thematic analysis employed a 'contextualist' approach, as it allows and acknowledges that participant's accounts are shaped not only by their individual experiences but also by a broader social context. Moreover, the semi-structured interviews were designed through pre-identified themes derived from existing literature, providing a framework. The contextualist approach lies between essentialism and constructionism, two other concepts in thematic analysis. An essentialist approach would focus more on reporting the participants accounts as direct reflection of the situation, while a constructionist approach would primarily focus on how discourses shape events and experiences (Braun & Clarke, 2006). This research, however, focusses on how individuals make meaning of their experiences within those discourses. The contextualist approach acknowledges the influence of existing knowledge and theory, while identifying shared narratives and recurring topics that emerge from the data. Aligning with emphasis on understanding the dynamic between the individual perspectives and the contextual implications (Braun & Clarke).

Preliminary Findings

The following findings result from a thematic analysis and give insights into the perspective and experiences of Aruban students' high school history education. The themes presented emerge after careful examination of the interview data. Therefore, these are not claims made on the 'reality', it merely provides an analysis on accounts of the participants' perceptions. To illustrate these points and give voice to the participants, direct quotes from the interviews are incorporated, presented in italics to clearly distinguish them.

Analysis of the interview data reveals a significant theme among participants, the disproportionate emphasis on Dutch history and influence. *'They are Dutch books with their biases'* and *'Obviously it's only about the Dutch and the Spanish that you know'*. This is expressed to go at the expense of other historical periods and understandings. One student perceived their history education as resulting in the creation of the narrative: '*We all knew the Netherlands were above us*'. Furthermore, the majority of participants mentioned in some form *"I think it should include the other perspectives, include other people's point of view, from other countries that also came here later on."* Other examples which were experienced to include a Dutch narrative were the period of Dutch colonization and the Second World War. Furthermore, multiple students followed up with answering that the focus was on what the Dutch went through during these historical periods, highlighting the absence of an Aruban perspective. In various ways, certain historical periods, regions and voices were neglected.

To give a brief insight into the wide range of answers mentioning something specific to be missing in the history content topics are ordered from most to least frequently mentioned; Aruban politics, relation within the Caribbean, world history, Aruba during the Second World War, Aruban food, history of the Aruban water plant, phosphate mining in Aruba, the Aruban history of vegetation agriculture and the Aruban relationship with the Dutch Kingdom.

Participants described their experience with learning history as *'passive'* and lacking critical thinking, discussions and exploring different interpretations. *'They just gave information and we had to write it down, it was not really discussed'*. History education in general was described to be 'mostly memorising, that is not what history is supposed to be'. Participants expressed a desire for a more diverse and inclusive content of history education.

Participants were asked to reflect on their connection students feel between the history curriculum and their cultural heritage via varying questions. Outside of the question directly being asked, often students mentioned their perspective while addressing the question on the scope of the history content, before the specific question was asked. A sense of disconnect from Aruban cultural identity is expressed in relation to the history education by the majority of the participants. '*We do have our own culture, but that does not get taught on*'. Multiple students also articulated a sense of missing out on the perspectives from people living on Aruba. They expressed interest in stories about the way Arubans on the island experienced historical events. *'I missed more perspectives, not just what is in the books. Visit places in the country, talk to locals, more details and stories.'*

In addition to this, students gave insights on how other sources of history, such as work, friends or family, did provide them with an understanding of more personal experiences. This allows students to create a link to the diverse background they, or other people in Aruba have. They mention how a lot of people migrated from different countries, which resulted in a multicultural society. This also means that not everyone automatically has family born on Aruba. One participant in particular explained that this was the reason they did not have access to this extra source on Aruban history, in turn connecting it to their want for history education to offer this information. Next to this, Aruban Cultural history was experienced by most students as being covered in a *'very surface level*', which lacked depth and specific examples. There was a variety of sentiments expressed in this part of the conversation. Give examples.

A duality was being highlighted between Aruba being a multicultural island, and the concept of a shared sense of community. Moreover, someone described how *'it is hard to pinpoint a true Aruban culture, because it is really multicultural*'. Participants followed up on this topic by emphasizing what they considered to be the importance of these varying perspectives. Reflections were often focussed on relating history to their national identity.

'My parents are not from here, if I had more information and context on Aruba, I would be more connected with the culture here.' Furthermore, this participant highlighted that they did not feel Aruban 'enough', especially compared to the extent of feeling connected to the culture of their parents. One described the following: Aruba is quite mixed, and do see that reflected in cultural events and music. But you do not see it in the history'. Next to aspects requiring improvements, various students expressed history education in an aspirational way as well, as a mean for creating a potential change. This was linked to the process of creating a broader concept of cultural identity, through history. Different students offer their perspective:

'Obviously, if you know your history, it makes you more connected to your place.'

'There are a lot of immigrants that come over with their own sense of identity who then migrate and commingle. And I feel like if we have a broader spectrum of history to share, to learn, that we can get their perspectives. And then we can become more of a community instead of feeling singled out and misunderstood because maybe some of your culture isn't shared with where you now live.'

'History education is important, it's going to make people feel more secure about their culture'.

'History education should play a role in building a national identity.'

'Education should play a role in feeling connected to each other on the island, especially in history. Because in history we learn about our culture. I missed that.'

This raises the point of a possible link being developed between history and people's cultural identity. Moreover, some participants linked a stronger sense of community, but also more involvement, to be enhanced through a history education which focuses more extensively on Aruba specific aspects. Lastly, a noteworthy suggestion contributed by a participant, was to create accessible sources of history education via projects outside of schools, as not everyone finishes high school.

In conclusion, themes identified following the reflections of students, consisted of a tension in Aruban history education. It is perceived by some as Dutch-centric and disconnected from local culture, while simultaneously it is recognized as playing an important role in relation to national identity and a sense of national community. Finally, students offered visions for the future. These included incorporating different perspectives and discourses into the curriculum, a more elaborative integration of Aruban culture, possibilities for creating a space for the multi-cultural identity and the transformative potential of history education in Aruba.

Discussion

How do the identified themes relate to the literature you described above?

Conclusion

This paper offers a preliminary exploration of Aruban high school graduates' perceptions of their high school history education. These preliminary findings, allow a start to the discussion that connects this, with challenges of nation-building in a postcolonial context. As part of a larger research thesis, the findings presented here are initial and should be interpreted as such. The experiences and perspectives of students suggest an alignment with earlier described literature, highlighting the need for decolonizing education systems and incorporating diverse perspectives to resonate with Caribbean identities (Hickling-Hudson, 2004). The findings indicate that in the majority of cases, these students felt that history was important and had a role to play in incorporating the diverse character of the Aruban community. However, the curriculum largely ignored extensive Aruban cultural and historical elements, as the dominant narrative favoured a single, Dutch perspective, consequently serving the disconnection between the history education and student's cultural identification. Further research is needed in order to better understand the challenges and opportunities which history education in Aruba faces, and to make a meaningful contribution to this discussion.

References

- Alesina, A., Giuliano, P., & Reich, B. (2021). Nation-Building and Education. The Economic Journal, 131(638), 2273–2303. https://doi.org/10.1093/ej/ueab001
- Allen, R. M. (2021). Migraties en de zoektocht naar inclusief cultureel erfgoed. In Antiliaans Erfgoed 1: Toen en Nu (pp. 121–142). Leiden University Press. https://scholarlypublications.universiteitleiden.nl/access/item%3A3244340/view
- Alofs, L. (2003). The Aruba Heritage Report. Aruba National Commission for UNESCO. https://www.creativeeuropedesk.nl/sites/default/files/files/UNESCO%20Aruba%20Heritage%20report%20Luc%20Alofs%20okt08_0.pdf
- Alofs, L. (2011). Onderhorigheid en separatisme: koloniaal bestuur en lokale politiek op Aruba, 1816-1955. UNOCA.
- Alofs, L., & Merkies, L. (2001). Kan ta Arubiano? Sociale integratie en natievorming op Aruba 1924-2001. VAD/De Wit Stores. https://hdl.handle.net/20.500.14473/840
- Barton, K. C., & Levstik, L. S. (2004). Teaching history for the common good. Lawrence Erlbaum Associates.
- Bentrovato, D., Korostelina, K. V., & Schulze, M. (Eds.). (2016). History can bite: history education in divided and postwar societies. V & R unipress. https://www.researchgate.net/profile/Denise-Bentrovato-3/publication/330688844_History_Can_Bite_History_Education_in_Divided_and_Postwar_Societies/links/5c4f6f0f458515a4c746d43f/History-Can-Bite-History-Education-in-Divided-and-Postwar-Societies.pdf
- Bhabha, H. K. (Ed.). (2013). Introduction: narrating the nation. In Nation and Narration (pp. 1–7). Routledge. https://www-taylorfrancis-com.utrechtuniversity.idm.oclc.org/chapters/edit/10.4324/9780203388341-1/introduction-narrating-nation-homi-bhabha?context=ubx&refId=b6f3da0f-f50e-41b9-8d90-e36e68536d50
- Boisselle, L. N. (2016). Decolonizing Science and Science Education in a Postcolonial Space (Trinidad, a Developing Caribbean Nation, Illustrates). Sage Open, 6(1), 2158244016635257. https://doi.org/10.1177/2158244016635257
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa
- Brett, P., & Guyver, R. (2021). Postcolonial history education: Issues, tensions and opportunities. Historical Encounters: A Journal of Historical Consciousness, Historical Cultures, and History Education, 8(2), 1–17. https://doi.org/10.52289/hej8.210
- Bryman, A. (2012). Social research methods (Fifth edition). Oxford University Press.
- Cain, A. (2017). A sense of belonging. LM Publishers / Editorial Charuba.
- Chapman, M., Eppinga, M. B., de Scisciolo, T., & Mijts, E. N. (2024). Pre-University engagement and education for sustainable development in Aruba: The Academic Foundation Year. https://doi.org/10.5167/UZH-236178
- Coördinatieteam Nationaal Onderwijsplan 2030, & Directie Onderwijs Aruba. (2019). Plan Educacion Nacional 2030 Nationaal Onderwijsplan "De lerende in de digitale samenleving". Proyecto Idioma den Enseñansa, Directie Onderwijs Aruba. https://www.ea.aw/pages/wp-content/uploads/e/eindtermen/havo-vwo/Geschiedenis-eindtermen-en-examenprogramma-havo-vwo-april-2022.pdf
- Creswell, J. W. (2007). When to Use Qualitative Research. In Qualitative inquiry & research design: choosing among five approaches (2nd ed, p. 39). Sage publ.
- De situatie van kinderen en jongeren op Aruba, UNICEF, 2013.
- https://www.unicef.nl/files/rapport_aruba__nederlands__webversie.pdf

- Departamento di Enseñansa Aruba. (n.d.-a). Secondary Education. Retrieved 1 April 2025, from https://www.ea.aw/pages/english/secondary-education/
- Departamento di Enseñansa Aruba. (n.d.-b). Primary Education. Retrieved 1 April 2025, from https://www.ea.aw/pages/english/primary-education/
- Durand, J.-L., & Kaempf, S. (2014). Reimagining Communities: Opening up History to the Memory of Others. Millennium: Journal of International Studies, 42(2), 331–353. https://doi.org/10.1177/0305829813512011
- Durrani, N., Kaderi, A. S., & Anand, K. (2020). National Identity and the History Curriculum: Nation Making in the Shadow of Partition. In P. M. Sarangapani & R. Pappu (Eds.), Handbook of Education Systems in South Asia (pp. 1–27). Springer Singapore. https://doi.org/10.1007/978-981-13-3309-5_41-1
- Eindtermen en Examenprogramma Algemeen Voortgezet Onderwijs Aruba. (2024). Departamento di Enseñansa Aruba (DEA. https://www.ea.aw/pages/wp-content/uploads/e/eindtermen/mavo/Geschiedenis-eindtermen-en-examenprogramma-mavo-4-april-2022.pdf
- Eriksen, T. H. (2002). Ethnicity and nationalism (2nd ed). Pluto Press.
- Faden, L. Y. (2015). Globalization and History Education: The United States and Canada. In J. Zajda (Ed.), Nation-Building and History Education in a Global Culture (pp. 51–65). Springer Netherlands. https://doi.org/10.1007/978-94-017-9729-0_4
- Fine, M. (1992). Disruptive Voices: The Possibilities of Feminist Research. University of Michigan Press. https://doi.org/10.3998/mpub.23686
- Golzar, J., Noor, S., & Tajik, O. (2022). Convenience Sampling. International Journal of Education Language Studies, 1(2). https://doi.org/10.22034/ijels.2022.162981
- Guadeloupe, F. (2009). Chanting down the new Jerusalem: calypso, Christianity, and capitalism in the Caribbean. University of California Press.
- Harris, R. (2013). The place of diversity within history and the challenge of policy and curriculum. Oxford Review of Education, 39(3), 400–419. https://doi.org/10.1080/03054985.2013.810551
- Hartog, J. (1961). Aruba Past and Present: From the Time of the Indians Until Today. De Wit. https://books.google.com/books?id=HWN7AAAAMAAJ
- Hickling-Hudson, A. (2004). Towards Caribbean 'knowledge societies': dismantling neo-colonial barriers in the age of globalisation. Compare: A Journal of Comparative and International Education, 34(3), 293–300. https://doi.org/10.1080/0305792042000257130
- Hickling-Hudson, A. (2007). Cultural complexity, post-colonialism and educational change: Challenges for comparative educators. International Review of Education, 52(1–2), 201–218. https://doi.org/10.1007/s11159-005-5592-4
- Hüning, M., & De Wilde, T. (2022). Aruba in een week: Observaties over taalbeleid en taalgebruik in het onderwijs op een meertalig eiland. Internationale Neerlandistiek, 60(1), 5–23. https://doi.org/10.5117/IN2022.1.001.HUNI
- Lévesque, S. (2008). Thinking historically: educating students for the twenty-first century (Reprinted in paperback). Univ. of Toronto Press.
- Lévesque, S. (2017). History as a 'GPS': On the uses of historical narrative for French Canadian students' life orientation and identity. London Review of Education, 15(2). https://doi.org/10.18546/LRE.15.2.07
- Liu, J. H., & Hilton, D. J. (2005). How the past weighs on the present: Social representations of history and their role in identity politics. British Journal of Social Psychology, 44(4), 537–556. https://doi.org/10.1348/014466605X27162
- Morgan, O. (2023). Whose story should we be telling? An exploration of student attitudes towards, and perceptions of, the British history curriculum. History Education Research Journal, 20(1). https://doi.

org/10.14324/HERJ.20.1.01
- Naeem, M., Ozuem, W., Howell, K., & Ranfagni, S. (2023). A Step-by-Step Process of Thematic Analysis to Develop a Conceptual Model in Qualitative Research. International Journal of Qualitative Methods, 22, 16094069231205788. https://doi.org/10.1177/16094069231205789
- Nuffic. (n.d.). Onderwijsinstellingen En Opleidingen - Aruba. Retrieved 1 April 2025, from https://www.nuffic.nl/onderwijssystemen/aruba/onderwijsinstellingen-en-opleidingen
- Oostindie, G. (2005). Paradise overseas: the Dutch Caribbean: colonialism and its transatlantic legacies (1. ed). Macmillan.
- Oostindie, G., & Klinkers, I. A. J. (2010). Dutch Rule in the Caribbean up until 1940: Careless Colonialism. In Decolonising the Caribbean: Dutch policies in a comparative perspective (pp. 57–63). Amsterdam University Press.
- Oostindie, G., & Stipriaan, A. van (Eds.). (2021a). Antilliaans erfgoed. 1: Toen en nu. Leiden University Press.
- Oostindie, G., & Stipriaan, A. van (Eds.). (2021b). Antilliaans erfgoed. 2: Nu en verder (pp. 1–7). Leiden University Press.
- Overheid van Aruba. (2023, June 19). Proyecto Scol Multilingual (PSML) [Page]. Overheid van Aruba. https://www.gobierno.aw/nl/proyecto-scol-multilingual-psml
- Pereira, J., & Alofs, L. (2023). CHAPTER 7 Papiamento: An Official Caribbean Creole Language from Legal Repression to Full Recognition. In A. Stipriaan, L. Alofs, & F. Guadeloupe (Eds.), Caribbean Cultural Heritage and the Nation (pp. 137–152). Leiden University Press. https://doi.org/10.24415/9789400604278-009
- Pijl, Y. V. D., & Guadeloupe, F. (2015). Imagining the Nation in the Classroom: Belonging and Nationness in the Dutch Caribbean. European Review of Latin American and Caribbean Studies | Revista Europea de Estudios Latinoamericanos y Del Caribe, 87–98. https://doi.org/10.18352/erlacs.9982
- Rasta, F., & the Gang. (2025, January 30). 1 for Unity' [Song]. https://www.youtube.com/watch?si=VrGlnRYCET61yIIS&v=sz3QirSc2U0&feature=youtu.be
- Said, E. W. (1994). Culture and imperialism (ist Vintage Books ed). Knopf. https://monoskop.org/images/f/f9/Said_Edward_Culture_and_Imperialism.pdf
- Sandhu, S., Harris, R., & Copsey-Blake, M. (2023). School history, identity and ethnicity: an examination of the experiences of young adults in England. Journal of Curriculum Studies, 55(2), 153–170. https://doi.org/10.1080/00220272.2023.2184212
- Stipriaan, A. van, Alofs, L., Guadeloupe, F., Granger, C., Allen, R. M., Baud, M., Cummins, A., Dijkhoff, R., Donald, S. M., Ferdinand, M., Florian, S., Geerman, P., Groenewoud, M., Jean, J. S., Hoefte, R., Hofman, C. L., McCree, R., Morris, A. J., Oostindie, G., … Ulloa Hung, J. (Eds.). (2023). Caribbean Cultural Heritage and the Nation: Aruba, Bonaire and Curaçao in a Regional Context. Leiden University Press.
- Taylor, T., & Guyver, R. (2014). History Wars and the Classroom: Global Perspectives. IAP - Information Age Publishing, Inc.
- The Central Bureau of Statistics and the Civil Registry and Population Office. (2022, September 21). A multicultural society. Central Bureau of Statistics. https://cbs.aw/wp/index.php/2022/09/21/country-of-birth-and-nationality/
- The Learner: Our Focus, A Strategic National Education Plan 2007-2017. (2007). Ministry of Education, Social Affairs, and Infrastructure Aruba. https://www.ea.aw/pages/wp-content/uploads/pdf/doc-pub/n/nop_2007-2017.pdf
- TurboScribe. (2023). https://turboscribe.ai/dashboard
- Wynter, S. (2003). Unsettling the Coloniality of Being/Power/Truth/Freedom: Towards the Human, After Man, Its Overrepresentation--An Argument. CR: The New Centennial Review, 3(3), 257–337. https://doi.

org/10.1353/ncr.2004.0015

- Zajda, J. (2015). Nation-Building and History Education in a Global Culture. In J. Zajda (Ed.), Nation-Building and History Education in a Global Culture (pp. 185–191). Springer Netherlands. https://doi.org/10.1007/978-94-017-9729-0_12

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A Whirlpool of Possibilities.

My personal experience on the island of Aruba can be explained through a metaphor of a powerful, intimidating, spiraling water anomaly. Arriving at this next chapter in my life started with a calm flow state. Scouting all my options both personally and academically, enjoying my new peaceful lifestyle, floating in the ocean. As time passed by, I was drawn to different possibilities: going on dives, entering the kiting world, sailing, playing beach volleyball, beach tennis, and deepening existing and building new friendships, while balancing the interviews for my paper. Initially, these activities brought excitement to my stay here, disrupting my calm floating state and moving me in different directions. But as each drawing force amplified, I got sucked deeper into each possibility, and suddenly the movement was too much. It was accelerating rapidly, and I found myself stuck in a whirlpool of possibilities pulling me in a hundred directions, while there was no way out as I was going deeper. Trying to keep everything under my control and fighting the current does not lead to a way out. I had to realize that I had to let myself go with the current, adjust to the circumstances, and the people around me. There were times when things were moving too fast, but in the end, the whirlpool spits you out and you are once again floating calmly at sea. The final week of my project was undeniably a pressure point during my stay, the bottom of the whirlpool. But now I am writing this reflection back in my initial calm flow state, enjoying my last days in this very special place.

While it was scary at some points, I certainly enjoyed the ride. I experienced exciting, beautiful, memorable moments that I can thank my wonderful friends for, who both accompanied me on this journey and threw me a lifeline if I started sinking. I want to thank Eric my academic and personal supporter, who provided help with any issue I brought to him. I am mostly thankful for

my parents and my brother, who are always there for me wherever I wander in the world. Lastly, I want to thank Aruba and its people, for accepting me and teaching me so much about the world and myself.

The Economics of Sunshine:
Exploring the Motives and Barriers for Solar Panel Adoption: A Perspective of Aruban Small- and Medium-Sized Enterprises

Zaránd Ferjancsik

1. Introduction

1.1 Context

The importance of renewable energy did not begin in 1992 in Rio de Janeiro at the Earth Summit or with the Paris Agreement in 2015. The power of the wind, the currents, and the sun have been utilized by households, traders, small businesses, and countries since the beginning of humanity. It was the rise in unsustainable and pollutive practices that pushed for global recognition and collaboration to address the issue of climate change and the implementation of sustainable development (Rio Declaration, 1992). The conference was followed with international applause and the world waited to see how the planet would be saved. In 1992, 88% of global primary energy consumption was supplied by fossil fuels, and by 2023, it was reduced to 83%, while in reality, gas, oil, and coal burning increased by 50%, increasing total greenhouse gas emissions (Ritchie, 2024). Increasing the share of renewable energy in the energy mix is crucial to reducing global greenhouse gas emissions while also having an immediate impact on local pollution (Timmons, 2014). While Small Island Developing States (SIDS) only contribute 1% of the global greenhouse gas, they are experiencing the adverse effects of climate change firsthand through escalating sea levels, coastal erosion, and increased frequency and intensity of extreme weather events (Havea et al., 2024). Despite the unfair consequences, energy transition on SIDS only leads to marginal differences in the numbers globally. Alternatively, sustainable initiatives can emphasize the importance of the issue and provide an example to other nations. Looking at Aruba, a SIDS located in the Southern Caribbean Sea off the coast of Venezuela, and its pollutive state of energy production, reliant on fuel imports and the huge potential for renewable energy, is a call for a closer investigation.

There are several economic consequences of relying on imported fuel to maintain. First, fuel prices have seen a global boom since the early 2000s, dragging energy prices with them, especially for markets that rely on fuel as an energy source. Secondly, oil prices also experience a high level of fluctuation (Awan et al., 2023). In the past, there was a social safety net established to balance out these fluctuations, but the continuous growth of fuel prices and lack of funding forced the government to stop the program (Ministry of Economic Affairs, Communication and Sustainable Development, 2023). These fluctuations lead to economic uncertainty as business owners want to predict their utility expenses, which are hindered by unpredictable energy costs. Consequently, enterprises not only suffer from the increasing energy prices but are simultaneously exposed to volatility. While utility scale solar makes up only 2% of WEB's electricity production (WEB, 2025), businesses in Aruba took the matter into their own hands and became spearheads of solar transitioning through

decentralized solar systems.. Countless studies have proved that solar panels are both a good way to increase energy independence and are an economical business investment (e.g. Rehman et al., 2007; Wampler, 2011; Manohar et al., 2015; Imteaz & Ahsan, 2018; Bruger & Henry, 2019). The work of previous scholars can be utilized to study the case of Aruba, but the unique characteristics of an island economy cannot be ignored when assessing the feasibility of an investment decision. Limited land and resource availability on islands require innovative and efficient solutions, as solar installations produce a comparatively low amount of energy per unit of land (Baker et al., 2013). For example, large areas of solar power plants may not be feasible, and rooftop solar may become the only way forward, where households and businesses play a key role in solar adoption. Availability of trustworthy information on the capacity, price, maintenance, and acquisition process, the lack of financial resources or access to financing options to cover the initial high investment, and technical difficulties, such as security, roof and electricity grid compatibility, meter box adjustment, and construction procedure are identified as main barriers to adoption taken from four separate studies focusing on different countries (Azabany et al., 2016; Pieloor, 2022; Hancevic & Sandoval, 2023; Hsbollah et al., 2023). This study explores the motives and barriers especially important or unique to SIDS, which is the first step towards overcoming the hurdles and understanding the case of solar panel adoption in Aruba.

1.2 Aim and Relevance

While Aruba pledged to achieve 100% renewable energy production by 2020 (Utilities Aruba, 2014), this promise fell short, as renewable energy production levels only reached 15% by 2024 (WEB Aruba, 2024). Similar pledges are made by governments all around the world with varying degrees of success (Lund & Mathiesen, 2009; Child et al., 2018; Zhong et al., 2021). Either way, they all face challenges due to the complex nature of the issue. This research aims to use community-based findings supported by a robust theoretical framework and quantitative evidence to assist humanity in facing these challenges. It contributes by closely examining one possible solution: decentralized solar energy production.

The study answers the research question: What are the motives and barriers to solar panel adoption for small- and medium-sized enterprises in Aruba? While the important role of commercial and residential solar panel adoption was introduced before, due to the limited land availability on an island, businessess are more likely to view solar panel adoption as aninvestment decision, making cost-benefit analysis a more applicable approach to the problem. The arguments to focus on small- and medium-sized enterprises (SMEs) over larger enterprises include that they are more flexible and freer to pursue new initiatives, while the investment decision has a bigger impact on their business, therefore, the costs and benefits are evaluated closer. Additionally, they are tied closer to the local community and offer a greater sample size.

The United Nations Sustainable Development Goal (UNSDG) 7 focuses on access to affordable, reliable, sustainable, and modern energy for all. This goal incorporates energy independence and renewable energy as two key drivers to a just and sustainable development by staying between the lines of social foundation and planetary boundaries, where humanity thrives in harmony with the environment (Raworth, 2018). Solar panel adoption by businesses is directly related to reduced greenhouse gas emissions and energy independence, therefore offering a clear path toward a modern, affordable, reliable, and sustainable energy source (Hancevic & Sandoval, 2023; Havea et al., 2024).

The aim of this study is to enhance understanding and provide actionable insights that can support local efforts for solar energy adoption and clearly define the economic

opportunities underlying solar energy. First, it has been argued that solar panels were proven as a profitable investment in other countries, and they offer energy independence for SMEs, empowering local businesses. Second, boosting solar panel adoption in Aruba expands the solar energy market, leading to job creation in a sector that is not directly tied to tourism, which is even more valuable in a tourism-dependent economy such as Aruba. Understanding the motives and barriers in place to these economic and social outcomes and the motivation behind individual businesses can be used to act on these factors to unleash the benefits of solar energy sustainably. While the literature is scarce, there have been case studies carried out to address the solar panel adoption of SMEs (Azabany et al., 2016; Pieloor, 2022; Hancevic & Sandoval, 2023; Hsbollah et al., 2023), but no available study was carried out on Small Island Developing States (SIDS). Similarly, there has been limited research on the roles and opportunities of renewable energy in Aruba (Weisser, 2004; Brendel et al., 2020; Croes, 2022), but there is not one focusing on SMEs. I aim to contribute to the literature by bridging these fields by focusing on solar energy adoption by Aruban SMEs.

1.3 Research Design and Structure

The methodology will contrast the economics of solar panels with qualitative insights gathered from community-engaged research. Multiple investment indexes, for example return on investment, net present value, and simple payback period will be calculated based on local data to assess the profitability of solar panels. The qualitative question will be answered by community-engaged research that utilizes semi-structured in-person interviews with owners and high-level managers of Small- and Medium-Sized Enterprises (SMEs) and solar experts in Aruba. The questionnaire is based on existing literature to explore how locals relate to hypothesized motives and barriers to solar energy while giving space to hear out aspects that are unique or overlooked. The comparison will aim to highlight the applicability or the reasons for the misfit of the literature on a small island economy and highlight the biggest motives and barriers to solar panel adoption.

The paper begins with a literature review. First, the economics of solar will be explored focusing on the financial aspect of the topic. Second, it will draw from complex economic theories and place solar panel adoption in the discipline. After reviewing the theoretical context, the research will follow. The different approaches will be explained in detail in the methodology section, and the findings will be presented under the results. The paper will close with a discussion and a short conclusion of the discoveries.

2. Literature Review

When assessing the feasibility of solar panel adoption, it is easy to adopt the narrow perspective of a financial analyst. Businesses depend on cash flows, profits, and long-term investments, for this reason, researchers might find cost-benefit analysis appealing while ignoring the complexities involved. Presenting Net Present Value (NPV) and Simple Payback Period (SPP) alongside insightful graphs can obscure the holistic nature of investment decisions. While the financial aspects of photovoltaic systems are undeniably important, this paper develops a multi-dimensional framework for a more comprehensive understanding of the subject. In addition to monetary considerations, various factors will be categorized into three dimensions: human, legislative, and geographic.

2.1 Economics of Solar Energy a One-Dimensional Approach: Money

The domain of cost-benefit analysis (CBA) is centered around the decision-makers who should only pursue an investment if the benefits outweigh the costs (Mourato, 2006). This definition is concise and to the point but is far from sufficient. What are the benefits, and what are the

costs? The initial concept of CBA originates from Jules Dupuit, a French economist in the 19th century, and he defined benefits as the social profitability of an investment (Sandmo, 2011). Yet, often, the "social" half of the phrase was forgotten, and CBA was all about monetary profits. There is a growing trend of involving the environment in CBA, as the value of the environment gained a small but growing value (Mourato, 2006). This section will serve as an overview of CBA employed on solar panels drawn from numerous studies.

For photovoltaic systems, the costs consist of the installation costs, degradation, and balance-of-systems costs, which usually refer to inverters, mounting hardware, and labor (Baker et al., 2013; Manohar et al., 2015; Imteaz & Ahsan, 2018; Hsbollah et al., 2023). Additional persisting costs surface through operational costs. While the direct costs of having solar panels are negligible, there are indirect costs, for example, through grid fees (Hsbollah et al., 2023). On top of the grid usage fee of 30, - Aruban Florin (AWG) paid by everyone connected to the electricity grid, Aruba has a standard fee of 15, - AWG per kWp solar panel installed (Elmar, 2022), which would be considered as operation cost. It is argued that the net operation costs decrease as photovoltaic systems reduce electricity costs for a business (Baker et al., 2013; Hsbollah et al., 2023). Additional benefits of solar are energy independence and, therefore, resilience to price and electricity fluctuations (Ministry of Economic Affairs, Communication and Sustainable Development, 2023). Considering the mentioned factors, in many countries the levelized cost of electricity (LCOE) is lower than purchasing electricity from the grid, and photovoltaic systems offering a cost effective alternative to the electricity provider companies;(Ram et al., 2018; Bódis et al., 2019; Hsbollah et al., 2023).

Focusing solely on these factors, the cost-benefit analysis appears straightforward. However, a variety of externalities impacting costs can complicate the outcomes. First, calculating the energy yield of solar panels is already a complex task, as the efficiency hugely depends on the angle, shading, temperature, and other impurity factors, such as dust and dirt (Manohar et al., 2015; Imteaz & Ahsan, 2018). Second, many governments around the world have different policies or subsidies in effect that can influence the CBA (Manohar et al., 2015; Imteaz & Ahsan, 2018; Vartiainen et al., 2019; Zhang et al., 2023). In Aruba, for example, there is a feed-in tariff (FiT) in effect that can further increase the benefits of solar, which only comes into effect when appropriate permits are obtained (Elmar, 2022). The government's position on solar panel adoption will be explored in detail in a later section. Lastly, solar panels are a long-term investment, as their life expectancy is 25 to 30 years (Rodrigues et al., 2016), calculating their NPV or SPP is subject to a high level of uncertainty. Technological advancements may alter electricity generation, and policies and electricity costs are subject to change, making calculations imprecise (Imteaz & Ahsan, 2018; Hsbollah et al., 2023).

The lack of environmental focus reflects the true nature of the available literature on CBA in photovoltaic systems. This also stems from the fact that businesses focus on the financial aspect and do not designate sufficient value to nature (Ministry of Economic Affairs, Communication and Sustainable Development, 2023). This argument cannot be generalized in Aruba, as its tourism-focused economy is highly dependent on the attractive nature of the environment, and many businesses depend on conserving these values. The government can play a role in assigning value to the environmental consequences, as on a macro scale the implications on the health of sustainable practices can be quantified. Manohar et al. (2015) calculate the externality costs of electricity generated from natural gas, as per capita health care costs for affected individuals, and the costs necessary to reduce the harmful effects of pollutants produced during power generation. By assigning a number to these consequences, the externalities can be internalized, and a more robust calculation can follow.

Large enterprises that have sufficient cash flow and room for experimenting with solar panels are also benefiting from economies of scale (Brugger & Henry, 2019). SMEs are faced with similar challenges as individuals who lack scale, flexible capital, and administrative staff and, therefore, are faced with a big investment decision that will reduce utility expenses, but at what costs? The decision is already complex, with only the financial aspect evaluated so far. Introducing additional dimensions complicates the process further, but it is essential for a comprehensive analysis.

2.2 Complexity 1: Human Dimension

Social Networks

The financial benefits of photovoltaics can be calculated using CBA, but it relies on the assumption that stakeholders have perfect information about the potential of solar. Looking at sustainable energy transition, humans are the slowest factors to change in this transition, leading to hurdles in sustainable technology adoption (Croes, 2022). The primary barrier to solar panel adoption identified by the Ministry of Economic Affairs, Communication and Sustainable Development (2023) is the low awareness and knowledge regarding photovoltaic systems' usefulness, cost-saving potential, and environmental implications. Academic literature supports this claim (Pieloor, 2022; Hancevic & Sandoval, 2023). This lack of awareness is compounded by the limited engagement within social networks, which can hinder the spread of important information about solar technology. Therefore, enhancing education and promoting social connections are crucial steps in addressing this barrier and facilitating greater adoption of solar panels. Social networks can play a crucial role in overcoming this obstacle and promoting solar adoption. Peer effects and social norms increase the likelihood that an individual will adopt a technology if they are socially linked to others who have already adopted it through two channels (Bamberg & Schmidt, 2003). First, through the exertion of social influence or pressure (Eppstein et al., 2011; Brugger & Henry, 2019). Second, through the provision of information (McCoy & Lions, 2014; Brugger & Henry, 2019). It was proven by Brugger and Henry (2019) that among individuals with closer relations, the diffusion of information is faster.

The interconnectedness of the actors plays a significant role in solar panel adoption, and for this reason, social network analysis (SNA) can be a useful tool to provide a better understanding of its consequences. SNA models the ties between social actors and offers a chance to explore patterns, so-called subgraphs, within a network (Scott, 2012). Such analysis requires a great amount of data points to work well. Therefore, this study employs an individual, ego-centric level analysis of the participants' social network and relies on the assessment of local experts to create a greater picture. Historically, individual clustering has undergone significant changes, but language proved to be a persistent cause (Scott, 2012). The role and effect of languages in Aruba, a multilingual state, requires extensive research and certainly contributes to language-based clustering on the island (Ngizwenayo, 2017). The effect of government incentivizing programs can also be evaluated using SNA. Brugger & Henry (2019) carried out a study on a model to evaluate the potential effects of various incentivizing programs. Their main findings highlight that segmented communities benefit less from the indirect effect of policies and lead to increased inequality, but the social equality consequences of incentives also vary with government strategy (Brugger & Henry, 2019). The government of Aruba has committed to raising awareness about solar panels and implementing policies aimed at reducing inequalities related to sustainable technology (Ministry of Economic Affairs, Communication and Sustainable Development, 2023). However, understanding the existing social networks and the effect of policies in place is crucial for the success of these initiatives.

2.3 Complexity 2: Legislative Dimension

Government Influence on Investment Decisions

Government policies and regulations significantly impact the costs and benefits of solar energy by employing subsidies, tax credits, renewable portfolio standards, and carbon pricing mechanisms (Hsbollah et al., 2023). The United States of America was the first nation to adopt incentives for solar energy through a 15% tax credit and implementing FiT (Wampler, 2011; Brugger & Henry, 2019). Governments can decide to focus on a technology-push or demand-pull approach (Baker et al., 2013). This paper focuses on the latter, as their impact influences the investment decision of the consumer. these subsidies focus on mitigating risks through reducing the up-front costs or increasing long-term profitability (Kastner & Stern, 2015; Brugger & Henry, 2019). An increase on the demand side in the medium and long run is followed by an increase in supply. New manufacturer and installer companies increase the competition in the market, driving technological advancements further and pushing the price down (Brugger & Henry, 2019). The effectiveness of policies is frequently assessed based on total adoption rates, often neglecting the implications for income equality. The most successful methods, especially during the early stages of solar transition, are the ones focusing on affluent agents, which exacerbates inequality (Brugger & Henry, 2019). On the other hand, programs targeting low-income individuals may result in slower overall adoption rates, they promote a more equitable transition to solar energy. (Brugger & Henry, 2019).

When considering the most government incentives for solar panel transition, in addition to their effect on the finances, the equality aspect also needs to be considered. The most common government policy regarding photovoltaic systems is FiT. There are two versions of FiT, gross and net (Flannery & Sahajwalla, 2013). While gross offers payment for the total amount of electricity generated by solar, regardless of whether it was used on location or if it was returned to the electricity grid (Imteaz & Ahsan, 2018). Net FiT or Net Metering, the more common one, also found in Aruba (Elmar, 2020), only reimburses for the excess electricity that was generated and loaded onto the grid (Imteaz & Ahsan, 2018). While differing in nature, both lead to higher long-term profits without reducing the initial cost barrier to adoption and primarily benefit those who can already afford solar panels, thereby promoting inequality (Brugger & Henry, 2019). Leasing programs are better in the sense that they reduce or eliminate up-front costs, as a third party owns the solar panels and leases them, making them more attainable (Brugger & Henry, 2019). While theoretically, these options are available equally to everyone, an imbalance still exists in the awareness of solar panels. Wealthier actors often have greater knowledge of solar panels and the capacity to go through the acquisition process. Additionally, private leasing companies prefer leasing to parties with more stable finances, as it reduces their risk. Lastly, Seeding refers to providing free or low-cost PV systems to a limited number of less affluent agents (Sundaram et al., 2024). As leasing, seeding reduces or removes the up-front costs, making them available to a wider audience. Targeting stakeholders who otherwise could not afford solar, further improving energy equality. Seeding also has great indirect effects, as the introduction of PV systems into new communities helps with information diffusion and educates the benefactor and its close surroundings about the potential of solar (Brugger & Henry, 2019).

2.4 Complexity 3: Infrastructure dimension

Economic Geography

The costs and benefits of solar energy differ considerably by geographic location, influenced by factors such as solar resource availability, electricity prices, and the existing grid infrastructure (Hsbollah et al., 2023). The study will employ

economic geography, which studies how activities are distributed across different geographical areas and how this distribution influences economic outcomes, exploring the relationships between the economy and physical locations while considering factors such as resources, transportation, trade, and regional development (Clark et al., 2003). First, Aruba has an abundance of solar radiation, with over 1600 solar hours per year, but lacks almost all other resources, creating an economically difficult position (Ministry of Labor, Integration and Energy, 2020). Like most SIDS, Aruba faces isolation, remoteness, poor connectivity, and generally underdeveloped technological sectors, reduce market attractiveness (Bakhuis, 2019). While debated, Aruba's tourism economy (Kapanadze, 2020; Peterson, 2020), complex political settings (Fruijtier, 2023), and high inequality (World Inequality Database, 2025) are all indicators of a developing state. Economic geography can also be used to identify underdeveloped regions, where buildings and the electricity grid appear as a barrier to solar panel adoption. As these infrastructural challenges appear geographically it accelerates the inequality between regions, and in segmented communities, dampens the indirect effect of incentivizing policies, therefore a geographical approach is also necessary when evaluating the overall impact of solar adoption.

Globalization has introduced both challenges and opportunities to Aruba's open economy (Ministry of Economic Affairs, Communication and Sustainable Development, 2023). In renewable energy, this allowed Aruba to import solar panels and benefit from technological advancements and lower prices (Peffley & Pearce, 2020). Additionally, globalization created a new market for renewable energy certificate (REC) trading. Through REC trading, Aruba could capitalize on its main natural resource, renewable energy (Bistline et al., 2019). Economic efficiency suggests that the distribution of wind and solar capacity added as a consequence of REC trading would equalize the marginal costs of generating electricity from renewable resources across different regions (Bistline et al., 2019), leading to total social welfare gain. The government of Aruba is exploring REC trading options to enhance renewable energy transition efforts (Ministry of Economic Affairs, Communication and Sustainable Development, 2023).

Decentralized Electricity Generation a Double-Edged Sword

Decentralized electricity generation offers a great path toward sustainable energy transition by increasing resilience, access, and environmental benefits. However, there is another side to the issue. Distributed generation (DG) undermines the utility and electricity providers. As mentioned earlier, the existing infrastructure can influence the feasibility of solar panel adoption, possibly creating a barrier (Pieloor, 2022; Hsbollah et al., 2023). The rapid adoption of photovoltaic systems can lead to grid congestion, as the electricity grid is not compatible with receiving such a high amount of electricity flowing from the opposite direction (Baker et al., 2013). Due to grid congestion, a ceiling has been imposed on solar panel adoption in Aruba, limiting businesses to a maximum installation of 100 kW per address if they wish to stay connected to the electricity grid (Croes, 2022). It was brought up during a stakeholder meeting to increase this cap, but the Ministry of Energy turned it down arguing that grid congestion is already an issue (Ministry of Economic Affairs, Communication and Sustainable Development, 2023).

Solar panels depend on the sun, and while the day-night cycle is predictable, weather events, such as rain or clouds, can lead to significant variations in electricity generation, which has to be compensated for by other sources (Baker et al., 2013). With a growing share of solar in the electricity mix, it becomes harder and harder to react to sudden changes, putting the electricity company in a difficult position. Aruba is completely isolated from the world in terms of electricity,

making the island's grid more fragile, as it cannot rely on the help of its neighbors (Croes, 2022). A solution often discussed is the implementation of energy storage, which would compensate for the intermittency of solar energy (Baker et al., 2013; Croes, 2022). While the development of energy storage is included in the action plan of the Ministry of Energy, the plans are still under preparation (Ministry of Economic Affairs, Communication and Sustainable Development, 2023).

Lastly, energy generation through photovoltaic systems represents a threat to the utility companies existing infrastructural and economic model (Peffley & Pearce, 2020). When solar panels offer a lower levelized cost of electricity than the electricity rates, people start shifting away from the grid, harming the utility company's earnings, which can be witnessed even in harsher environments (Kantamneni et al., 2016). A conflict of interest surfaces, as the electricity company is often owned by the government, which incentivizes solar panel adoption, while the electricity company has to deal with backlash. Some utility companies around the world create hurdles to solar panel adoption by altering structures, shifting control, and legal maneuvers to slow down the transition to stay in control (Prehoda et al., 2019). Therefore, next to infrastructural difficulties, investors in solar panels also have to navigate the battles with the electricity company, which could construct additional barriers to adoption.

3. Methodology

3.1 Financial Feasibility Analysis

The literature review has shown how assessing the feasibility and consequences of solar panel adoption cannot be solely based on a simple profitability calculation. This study upholds this claim; however, understanding the financial benefits of solar panels is still crucial when approaching this topic, therefore a handful of calculations were carried out to acquire various financial feasibility indicators. A common tool for calculating these metrics is the RetScreen software, which computes the Net Present Value (NPV), Simple Payback Period (SPP), and Internal Rate of Return (IRR) based on specific inputs. For this reason, these indicators have become popular when evaluating the profitability of energy investment (Rehman et al., 2007; Wampler, 2011; Poullikkas, 2013; Manohar, 2015; Rodrigues et al., 2016; Imteaz l& Ahsan, 2018). Another common metric that has surfaced in literature is the Return on Investment (Pearce et al., 2009; Kang & Rohatgi, 2016). While not necessarily a profitability indicator, Levelized Cost of Electricity (LCOE) is often used as a method to calculate the price of electricity, which is mostly used to compare the cost efficiency of different energy technologies (Branker et al., 2011; Baker et al., 2013; Oladokun & Asemota, 2015; Kang & Rohatgi, 2016; Chadee & Clarke, 2018, Lai et al., 2021). This methodology will introduce the input variables used, and how each metric was calculated.

A discount rate of 5.41% was assumed from the latest overnight lending facility rate issued by the Central Bank of Aruba (2024, August). This rate is nominal, as borrowers would pay this rate in nominal terms including inflation. The inflation rate of 3% was calculated with a tool issued by the Central Bureau of Statistics (2025). The updated version of the above-mentioned RetScreen software was used to retrieve the monthly solar radiation on a flat surface (RetScreen). As the climate of Aruba is very stable, it was assumed that a business uses the same amount of electricity every month of the year. In Aruba, the current electricity tariff for small- and medium businesses is 0.5444 AWG/kWh (Elmar, 2024 November). The FiT for commercial is 50% of this rate, which is 0.272, additionally, Elmar charges 15,- AWG per installed kilowatt peak (kWp) solar, which was included in the calculations (Elmar, 2022). As there is no available electricity escalation rate for Aruba, the regional value of the Caribbean was taken, which is 2.08% (Olade, 2025). A hypothetical tender was sent to the three biggest

solar panel installer companies, and the rates and the type of photovoltaic models were requested for a 10 and 100 kWp system. The average of the submitted input was taken in terms of installation cost, the true size (two companies offer 440 W elements, therefore a 10 kWp system's true capacity is 9680 Wp), efficiency, and the degradation rate of the models. For this modeling exercise, only upfront payments were considered. An industry standard of a 25-year life cycle was assumed for the investment. All calculations were made with Python version 3.12.7 and are publicly available on GitHub at zazaferjancsik/ SolarProfitabilityCalculation.

The nature of cash flow from investing in solar is as follows. In the first year, there is the expense of the installation cost, let us say on the day the solar panel gets plugged in and starts producing electricity. From this point onward, it produces monthly income of the amount of electricity generated times the price of the electricity through saving on the utility bill. As time passes by, the degradation rate of the solar panel is deducted from its efficiency capacity, but the price of the electricity also rises by the escalation rate. Additionally, if the production is higher than the consumption of electricity, the income changes to the amount of electricity consumed times the electricity rate (saved on the utility bill) plus the income generated from the FiT (which also grows due to electricity rate escalation). It is crucial to calculate the cash flow on a monthly basis, as Elmar does net metering at this frequency. Next to the installation cost, the solar panel fee of 15, - AWG also needs to be taken into account. While this rate remained the same since its introduction, at some point this rate will be adjusted due to inflation. While this moment cannot be predicted, for the sake of the calculations, the grid fee was a subject to inflation rate.. This logic was used to determine the cash flows of the investment, and underly the calculations for the profitability indicators.

The first, and most widely used indicator NPV, is calculated by discounting the value of future incomes and expenses, by dividing them by one plus the discount rate to the power of the year when the transaction will occur. The ROI is an alternative way to showcase the NPV, where the NPV is divided by the total discounted expenses, and presented in a percentage form. The SPP shows the moment when the incomes surpass the expenses, or in other words, the venture pays itself off. This value represents the first month where the NPV of the investment is positive. The IRR shows the discount rate when the NPV is 0. If the IRR is greater than the discount rate, the investment is generally considered favorable, as it suggests the project will yield a return exceeding the cost of capital. This value was calculated using an iterative method, therefore an algorithm kept trying to find the IRR until the NPV proved to be 0 with a precision of 0.0001. Lastly, the LCOE is the NPV of the cost of the electricity. It is calculated as the discounted total expense divided by the discounted total amount of electricity generated during the photovoltaic system's lifetime, showing how much energy was generated for each AWG invested into the equipment.

All indicators were calculated for a 10, 50, and 100 kWp system, as a function of the monthly electricity consumption, and graphed for visualization purposes. For NPV, IRR, ROI, and SPP, for each system the case of a delayed permit was included, to expose the effect of the bureaucratic hurdle on the investment value, in that case, the owner did not receive income from feeding for the first two years. For LCOE the case of no solar fee was also included, to illustrate the effect of the 15, - AWG/kW solar on the cost of electricity, in which case the total expense of the project is the installation cost. Lastly, a function was developed based on the assumption that the cost of solar installation increases linearly, to determine the solar system that yields the highest NPV for each level of monthly electricity consumption.

3.2 Stakeholder Interviews

While the economic feasibility analysis is crucial to identify if investing in solar panels is desirable for SMEs, there are

several complexities underlying investment decisions that NPV or SPP cannot measure. To uncover non-fiscal factors influencing decision-making, semi-structured interviews were carried out with stakeholders, which is regarded as crucial for qualitative research (Gioia et al., 2013). Previous scholars have utilized different methods of data collection, primarily surveys and interviews. While each approach has its set of advantages, projects employing surveys in Aruba were faced with low response rates, and considering the small sample size, interviews are the favored method. All interviewees operate in Aruba, ensuring community-engaged research, which is determinant to reflect the unique perspective of islanders.

Semi-structured interviews are structured in the form that there is a set of questions prepared before the interview based on academic literature and preparatory interviews. This ensured that all dimensions of the research were discussed. The list of questions prepared had minor adjustments based on the position of the stakeholder to better match their expertise, and are available upon request from the author. However, rather than an interrogation, the conversation was natural, leading to deviation in order, depth, and focus of topics. This form of data collection gave freedom to the participants to focus on issues they find important and introduce unexpected themes.

All participants conduct business in Aruba and have experience with solar panels; they fall under two categories. First, solar energy experts are either employed at private solar companies on the island or work with government and government-owned enterprises. Second, employees/owners of SMEs with solar panels who reflect the true perception of solar panel adoption. From the initial 48 invitations, in the end, 6 solar experts and 8 SMEs were interviewed. The sampling followed the snowball method relying on personal networks and online research. Solar experts reported a very high response rate of approximately 86%, while SMEs demonstrated a significantly lower interest, with only a 19.5% response rate, this discreptancy could be explained by higher interest in the research among experts in the field.

Participants were invited for an interview via email or text message, where they were only informed of the title of the study, privacy concerns, and the voluntary nature of the study. Upon showing interest, face-to-face interviews were scheduled for one exception, which happened via a Zoom call. The interviews included in the research were audio recorded. The interviews began with verbal consent from the participants to the recording, and privacy rights to ensure transparency, diplomacy, and discretion, which is critical for qualitative research (Gioia et al., 2013). After the interview, all participants were recontacted and invited to a symposium where the findings were presented and were provided with a copy of the final version of the paper. This ensured the maintenance of good relations and allowed them to identify any distortion in the results.

To analyze the results all audio recordings were transcribed with the software Turboscribe.ai and were corrected by the researcher if there were any mistakes. The frequency of motives and barriers mentioned were collected from all interviews. Both the total number of mentions and the consistency between the two groups were considered to identify the biggest motives and barriers and the disruption between the perception of experts and adopters.

4. Results

4.1 Financial Feasibility Analysis

The calculated values of the financial feasibility indicators can be viewed in Figure 1 to 6. A general pattern that can be identified is that a larger solar installation is more profitable with higher electricity consumption, and the value of an investment converges above a point.

Looking at the NPV results in Figure 1, if there was no permit, for any level of electricity consumption a larger investment would be more valuable, and any installation has a positive value. However, once the permit is taken into

consideration, the 50 and the 100 kWp systems become economically undesirable, below 2000 and 4000 kWh monthly consumption respectively. The consumption level is also significant, as different thresholds indicate where each system attains its highest value. The IRR presented in Figure 2 aligns with the NPV results; both indicate values greater than the discount rate if no delays are present. Conversely, with delays, businesses with low levels of electricity consumption and high levels of electricity production would face IRR lower than the discount rate, or even negative values, meaning that there is no possible discount rate, where the project would pay itself off, as without FiT the produced electricity does not capitalize. Similarly, the ROI in Figure 3, exhibits tremendous returns in the absence of permit delay, reaching 380%, meaning almost a quadrupling of the initial investment. However, investors depending on their electricity consumption, who overlook the permit process risk losing half of their initial capital. A beloved indicator by entrepreneurs the SPP, conveys the same story in the simplest manner in Figure 4. In most cases, the payback time is 2.5 to 4 years, however, there is a possibility that the project never pays back the investment, as indicated by the discontinuous lines.

The LCOE in Figure 5, tells a different story. The levelized cost of electricity does not depend on the monthly consumption, as it does not affect electricity production or costs, therefore it is a horizontal line. Bigger projects have a lower LCOE, however, the difference in LCOE between the 10 kWp and 50 kWp systems is significantly greater than that between the 50 kWp and 100 kWp systems, suggesting diminishing returns. The bright line represents the utility rate of the electricity, the cost a business pays for electricity if it does not have its own electricity source. The LCOE of all solar projects is almost a quarter of this price.

Lastly, in Figure 6 we can see that there is a positive linear relationship between the highest NPV for a given monthly kWh consumption and the number of solar panels installed. This can be inferred from Figures 1 to 4, as in each case there is a point in monthly consumption level where the bigger installation overtakes the smaller projects in terms of profitability. The horizontal line at 100 kWp represents the legal ceiling for solar installation for businesses, emphasizing that even though above 4000 kWh monthly electricity consumption by installing more solar would be financially more profitable, it is not attainable with the current policies.

Figure 1 Net Present Value of a 10, 50, and 100 kWp solar systems as a function of monthly electricity

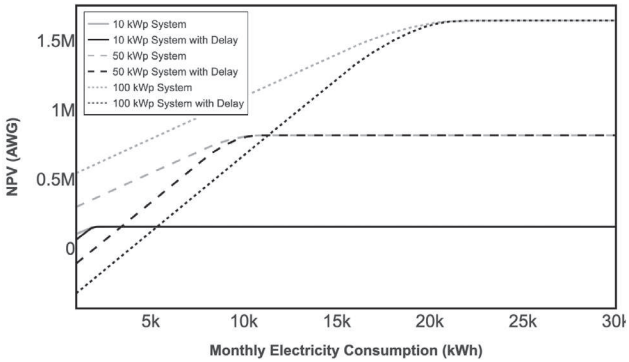


Figure 2 Internal Rate of Return of a 10, 50, and 100 kWp solar systems as a function of monthly electricity

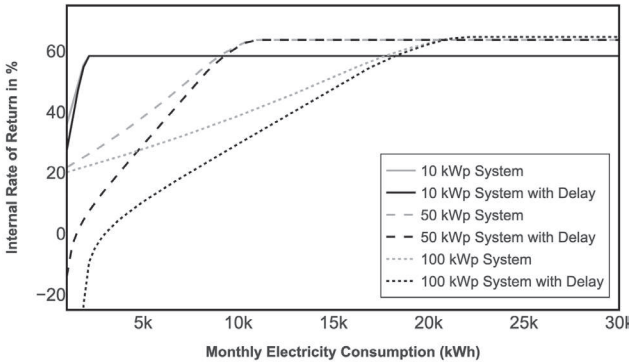


Figure 3 Simple Payback period of a 10, 50, and 100 kWp solar systems as a function of monthly electricity

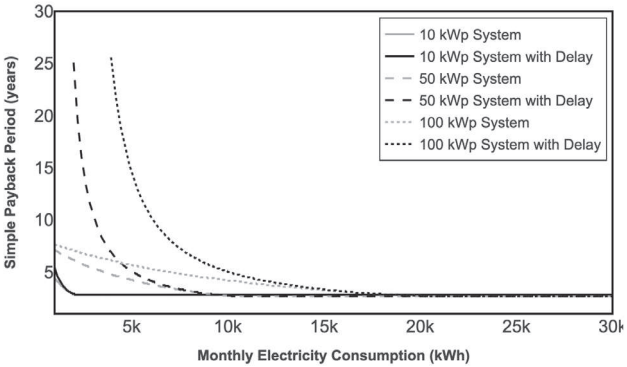


Figure 4 Return on Investment of a 10, 50, and 100 kWp solar systems as a function of monthly electricity

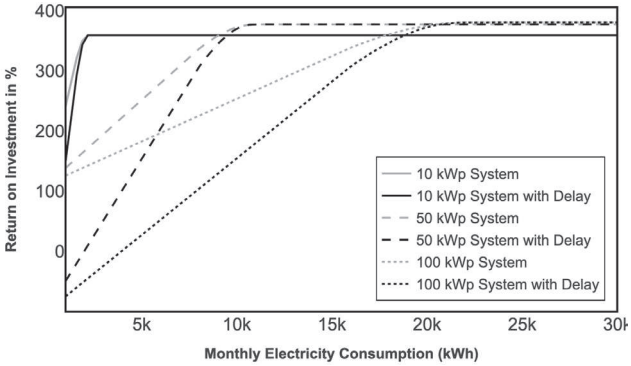


Figure 5 Levelized Cost of Electricity of 10, 50, and 100 kWp solar systems as a function of monthly electricity

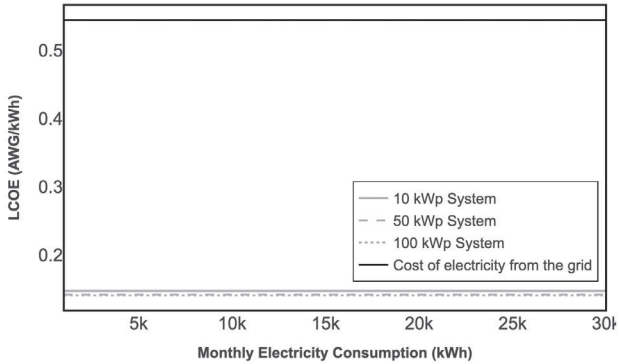
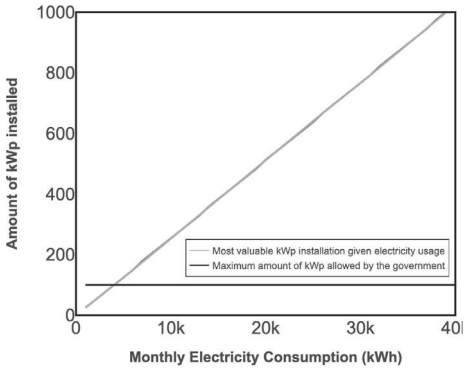


Figure 6 Most valuable kWp system in terms of NPV for a given level of monthly electricity usage



The graphs illustrate significant patterns and relationships between profitability, the amount of solar installed, and electricity consumption, highlighting the complexity of solar adoption dynamics. The individual and social consequences are explored in the discussion chapter after the motives and the barriers to solar panel adoption brought up during the stakeholder interviews are presented in the next section.

4.2 Stakeholder Interviews

The results of the interviews are summarized in Table 1. While numbers can give a good superficial understanding of the topic, the following paragraphs will explore all motives and barriers, and provide context drawn from the interviews, that can be used for a more encompassing discussion.

Not one participant identified a single motive for investing in solar, it was always a composition of multiple factors. For this reason, the participant was asked to identify the main driver of their final decision. The most common incentive mentioned in all interviews was the financial benefit of solar panels, solar companies claimed 1.7 to 3 years of payback period, and the companies that tracked their numbers reported a slightly higher 2-to-4-year period. All experts agree that monetary incentive plays the biggest role behind solar panel adoption on the island among firms, and the enterprises that had different key motives for adoption expressed that this investment was insignificant considering their cash flow. Seemingly the motivation to be sustainable was a close second place, as everyone except two participants brought it up. However, only two companies claimed that the main motive behind solar panel adoption was environmental reasons. The effect of solar panels on the corporate image was found important by most businesses, however only one of the local solar companies mentioned it. For different companies, the image was important for different reasons, while three companies argued it is more important for customer perception, two companies argued, that it is more beneficial to attract investors. Energy independence was found to be the smallest driver of solar panel adoption, only brought up in three conversations.

Table 1 Motives and Barriers to Solar Panel Adoption (brackets indicate the main motive))and barrier)

FACTOR	SMES	EXPERTS	TOTAL
MOTIVES			
FINANCIAL GAIN	8 (5)	6 (6)	14
SUSTAINABILITY	7 (2)	5	12
CORPORATE IMAGE	6 (1)	1	7
ENERGY INDEPENDENCE	2	1	3
BARRIERS			
COSTS	4 (1)	2	6
LACK OF INFORMATION	1	2 (2)	3
BUREAUCRATIC PROCEDURE	5 (3)	5 (2)	10
ELECTRICITY GRID	7 (3)	6 (2)	13
BUILDING COMPATIBILITY	1	2	3
OWNERSHIP	1 (1)	1	2

Source: Stakeholder Interviews

Similarly in the case of barriers, after a participant listed numerous obstacles to installing a photovoltaic system, they were asked to name the biggest hurdle. The most common and biggest barrier was issues with the electricity grid. All experts are aware of the constraints stemming from the electricity infrastructure, and only one business had no complaints on the topic. Both companies and experts complained about the congestion of the electricity grid, leading to voltage problems, or some areas on the island being blocked for further installations. While mentioned less frequently, bureaucratic procedures were identified as a significant hurdle in Aruba. The primary bureaucratic hurdle discussed was the permit acquisition process. While most participants agree that it generally takes 6 to 12 months to acquire the permit, three of the eight companies had complications that doubled the length of this process. Other barriers that were brought up are the cost of the investment, lack of information on solar panels, which was identified as a key barrier by two experts, and ownership of the property, also claimed to be a main obstacle by a business owner.

This section outlines the motivations and barriers, providing important context to the numbers presented in Table 1. The subsequent chapter will delve deeper into these issues, exploring the underlying reasons, addressing any discrepancies, and identifying potential pathways for improvement in solar adoption.

5. Discussion

This section contrasts the different findings of the research and provides a possible explanation based on the literature. Additionally, the implications for businesses and the government are mentioned. Lastly, the limitations of the study and suggestions for further research are discussed.

5.1 Quintessential Quantitative and Qualitative Qualifiers

The number one motivation for solar panel adoption is the financial benefit, which is not surprising looking at the profitability indicators, which prove the underlying opportunity of this investment. Both the calculated and the reported values of SPP, are considerably shorter than recent studies in different countries, which in Poland is 8 years (Niekurzak & Kubińska-Jabcoń, 2021), in Thailand is 6 to 17 years (Leewiraphan et al., 2023), and in Pakistan is 2.3 to 6.8 years (Uddin et al., 2022). Similarly, the greatest barriers identified during the interviews, the bureaucracy and the electricity grid are also reflected in the quantitative part. The effect of the bureaucratic process on earnings is evident. The issue underlying the permit process is a combination of numerous factors. Stakeholders mentioned that in Aruba, there are too many parties involved in acquiring the permit, there is a lack of staff approving permits, and backlogs become a rising issue lengthening the acquisition time. The issues arising from the electricity grid are also felt in different ways. First, some businesses do not have the option to install solar, as the local grid is already full. Second, as supported by Figure 6, businesses are constrained by the 100 kWp installation limit, keeping them from reaching their full potential. Some SME participants exhibit frustration claiming that they could install far more solar, without feeding into the electricity grid. A more elaborate policy is demanded, which is more inclusive in terms of different enterprises and technology. Batteries a potential solution to grid congestion and energy intermittency (Baker et al., 2013; Croes, 2022), are also not incorporated into the current policy (Elmar 2022). The number one barrier to solar panel adoption claimed by the Ministry of Economic Affairs, Communication and Sustainable Development (2023) is the information barrier. This study cannot support this claim, as multiple parties interviewed expressed the opposite, saying that solar panels are a popular topic on the island at the moment, both among individuals and also in

the media through advertisements. An ego-centric analysis revealed that most participants discuss solar energy within their networks, pushing solar adoption through the spread of information and peer effect.

5.2 Implications

Businesses can utilize the results of this study to decide whether to adopt solar panels or not. While each case is unique, this paper shows the monetary potential of the investment, while warning about the effect of the permit process, and grid congestion. This study alone should not be used as a base for decision-making, as there are numerous limitations, which are discussed later. A profitable investment can aid businesses in gaining stability, and through reducing their utility expenses increase profits. Additionally, solar companies can utilize the motives in their marketing by focusing on the financial and environmental benefits of solar; and offer help in overcoming the barriers to reach a wider consumer group by offering off-grid solutions and speeding up the permit process.

Solar experts claim that the speed of solar adoption in Aruba is fast. The backlogs in the permit process and the congestion of the grid serve as evidence of this claim, as Elmar and other organizations struggle to keep up with this transition, implicating that indeed the human factor is the slowest factor to change (Croes, 2022). There is currently no solution, and the grid will keep filling up faster than the upgrades happen, and backlogs are not clearing out. Government intervention needs to happen before it reaches a "tipping point", a threshold beyond the consequences is devastating (Singh et al., 2022). Gradual changes need to be implemented, soon, to prevent abrupt ones, as seen in Hawaii, where suddenly Net Metering was shut down completely surprising the market. The investment value and therefore the attractiveness of solar panels plummeted shocking the solar industry and leading to approximately 2000 lost jobs (HSEA, 2023). The equality consequences are also undesirable, as the wealthy have already adopted solar, and the consequences affect the less fortunate more severely. The current FiT scheme is an example of a government policy that escalates energy inequality; however, the market was so inviting that private companies started lease-to-own programs, which is a form of leasing, offering a solution to the high initial costs, leading to more inclusive adoption. The findings of this study can be used by the government to reevaluate the current policies and consider the potential benefits, dangers, and social implications of decentralized solar.

5.3 Limitations and Further Research

This study acknowledges the complexities behind solar panel adoption and includes both a quantitative and qualitative approach. These methods correct one another greatly, however, there are still some limitations, that need mentioning. The calculations are subject to high uncertainty and therefore risk. The capacity of the solar panels is usually not at the peak value, as they are subject to the impurity factors mentioned (Manohar et al., 2015). The inflation rate and the energy escalation rate are only a prediction, the real future prices may differ greatly. The policies are also subject to change, and all these ambiguous factors lead to uncertainty in the calculation, which can lead to low confidence in the investment (Imteaz & Ahsan, 2018). While the qualitative interviews were carried out with academic rigor, the findings would be more robust, if non-adopters were included in the sample, if more interviews were carried out, and if inter-rater reliability was established.

This paper contributes to the literature by creating and employing an elaborate framework for the motives and barriers behind solar panel adoption on SIDS. While the research tapped into several factors influencing the adoption and the consequence of decentralized solar, further research is required to create a deeper understanding of each factor.

For example, a study can focus on how consumers and investors consider the sustainable image of a business. The model evaluating the importance of social networks created by Brugger & Henry (2019) would benefit from empirical research, to truly evaluate the effect of incentivizing policies on social equality. The calculations of this study lack an environmental aspect, and a further study could internalize the effect on health and the environment, by assigning monetary value as proposed by Manohar et al. (2015). This study focuses on SMEs for reasons outlined in the introduction, and a similar study can be carried out on residential solar would be a relevant expansion to the literature. Additionally, studies can focus on proposing solutions to the barriers identified by this paper, for example through examining potential solutions to grid congestion, or by studying the permit acquisition process. Lastly, a GIS study can be carried out to examine the geographic discrepancies and clustering of solar adoption, which would provide a better understanding of the geographic dimension of the issue.

6. Concluding Remarks

This study went beyond a simple cost-benefit analysis for solar panels. Three new dimensions of influencing factors were introduced that require essential qualitative research. To unravel the true motives and barriers to solar panel adoption for SMEs in Aruba two methodologies were adopted. First, an independent financial feasibility analysis, which already built on some of the complexities introduced. Second, to fully encompass the qualitative aspects, community-engaged research was utilized, to reflect the realities of local businesses and experts. The results acquired from the two approaches were combined to paint one cohesive picture of the factors influencing the adoption of photovoltaic systems. The main motivation identified was financial benefit, closely followed by sustainability. Energy independence and corporate image were also mentioned as motives, although by less participants. The biggest barrier to solar panel adoption is the issues arising from the electricity grid, slightly less relevant but still a significant hurdle is the bureaucratic process. Other obstacles mentioned during the semi-structured interviews are initial costs, lack of knowledge about solar panels, building compatibility, and ownership of the building.

Previous scholars in the field have carried out similar calculations, and interviews. This study finds its place in the academic literature by combining methodologies and focusing on under-researched SIDS. The findings of this paper can be used by Aruban SMEs, solar companies, and the government to enrich their understanding of the factors underlying solar panel adoption, and the consequences thereof. Furthermore, by focusing on decentralized solar, this study contributes to the UNSDG 7, as solar panels offer both an emission-free electricity source and increase the energy independence of both businesses and Aruba.

References

- Azabany, A., Azabanee, A., Khan, K., Shah, M., & Ahmed, W. (2016). Analysis of an SME using silicon and flexible organic solar cells as replacements for fossil fuel sources of electricity in UK and Iraq. Journal of Environmental Science and Engineering B, 5(4). https://www.davidpublisher.com/Public/uploads/Contribute/5769f1169c056.pdf
- Baker, E., Fowlie, M., Lemoine, D., & Reynolds, S. S. (2013). The economics of solar electricity. Annu. Rev. Resour. Econ., 5(1), 387-426. https://www.annualreviews.org/content/journals/10.1146/annurev-resource-091912-151843
- Bamberg, S., & Schmidt, P. (2003). Incentives, morality, or habit? Predicting students' car use for university routes with the models of Ajzen, Schwartz, and Triandis. Environment and behavior, 35(2), 264-285. https://journals.sagepub.com/doi/abs/10.1177/0013916502250134?casa_token=yATCJzH-VqIAAAAA:ty2V8tirUQJ5WB26kqxqd5poN-s4TO42NZH2K6LJ8qQAUbJvja2XZ025bxp-4FYy6UmAtj5yaoJBE&casa_token=KX4IqSH-vUPcAAAAA:rAyck8Yhu2iD8eDKJRJeYX6XyN2s02rRMisgQ3CU1j11RgvFcdM0YjkUC1ebSL17iI5tr8C5r1A
- Bistline, J., Santen, N., & Young, D. (2019). The economic geography of variable renewable energy and impacts of trade formulations for renewable mandates. Renewable and Sustainable Energy Reviews, 106, 79-96. https://www.sciencedirect.com/science/article/pii/S1364032119301194
- Bódis, K., Kougias, I., Jäger-Waldau, A., Taylor, N., & Szabó, S. (2019). A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/J.RSER.2019.109309.
- Branker, K., Pathak, M. J. M., & Pearce, J. M. (2011). A review of solar photovoltaic levelized cost of electricity. Renewable and sustainable energy reviews, 15(9), 4470-4482. https://www.sciencedirect.com/science/article/pii/S1364032111003492?casa_token=02nkA48l3lAAAAAA:o_xLv9An1N-513iOLJoo2HqNeUsm1uXWnqSs09s29ugXJL0e-sumulWacP7H81JR645baeSmMUqw
- Brugger, H. I., & Henry, A. D. (2019). Equity of Incentives: Agent-Based Explorations of How Social Networks Influence the Efficacy of Programs to Promote Solar Adoption. Complexity, 2019(1), 4349823. https://onlinelibrary.wiley.com/doi/full/10.1155/2019/4349823
- Centrale Bank di Aruba. (2024, August 5). Table Lending Facilities Program rates of the Centrale Bank van Aruba. Retrieved April 2, 2025, from https://www.cbaruba.org/readBlob.do?id=17085
- Central Bureau of Statistics. (2025, March 27). Inflation Calculator. Accessed March 29, 2025, at https://cbs.aw/wp/index.php/2024/11/06/inflation-calculator/
- Chadee, X. T., & Clarke, R. M. (2018). Wind resources and the levelized cost of wind generated electricity in the Caribbean islands of Trinidad and Tobago. Renewable and Sustainable Energy Reviews, 81, 2526-2540. https://www.sciencedirect.com/science/article/pii/S1364032117309930?casa_token=WTc0cTCnzW8AAAAA:Ivpvoph1yI0-SNSPpR4BiPf0YmoJTKfL-H4odvq62KDCedhgpXDZTSMaBlNxWyyPyNYV-vkbbeNA
- Child, M., Ilonen, R., Vavilov, M., Kolehmainen, M., & Breyer, C. (2019). Scenarios for sustainable energy in Scotland. Wind Energy, 22(5), 666-684. https://onlinelibrary.wiley.com/doi/epdf/10.1002/we.2314
- Croes, G. (2022). A Sustainable Energy Transition Case Study On Aruba (Doctoral dissertation, Delft University of Technology). https://repository.tudelft.nl/file/File_2cb37ea3-047e-4adc-89fc-3df2da545016?preview=1
- Eppstein, M. J., Grover, D. K., Marshall, J. S., & Rizzo, D. M. (2011). An agent-based model to study market

penetration of plug-in hybrid electric vehicles. Energy policy, 39(6), 3789-3802. https://www.sciencedirect.com/science/article/pii/S0301421511002904?casa_token=dDbbIGW9I-IAAAAA:Otpn69CEVT-WvEu4xzrd7eHJ5CMcEoiDIV0APZQyKIf0ikvST-nUneP5jEFNlVoMuHTMucJ40g

- Flannery, T., & Sahajwalla, V. (2013). The critical decade: Australia's future–solar energy. https://apo.org.au/node/35453
- Fruijtier, T. (2023). A switch from Dutch to Papiamento: The Aruban debate on the possible switch to Papiamento as the instruction language within the Aruban education system UAUCU Undergraduate Student Research Exchange Collected Papers 2023. 51-66.
- Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. Organizational research methods, 16(1), 15-31.
- Hancevic, P. I., & Sandoval, H. H. (2023). Solar panel adoption among Mexican small and medium-sized commercial and service businesses. Energy Economics, 126, 106979. https://www.sciencedirect.com/science/article/pii/S0140988323004772
- Havea, P. H., Su, B., Liu, C., Kundzewicz, Z. W., Wang, Y., Wang, G., ... & Jiang, T. (2024). Wind and solar energy in Small Island Developing States for mitigating global climate change. iScience, 27(10). https://www.cell.com/iscience/fulltext/S2589-0042(24)02287-9
- Hawaii Solar Energy Association. (2023, December, 20). Hawai'i Utilities Commission Slams Door on Rooftop Solar. Retrieved online on April 3, 2025 from https://hsea.org/wp-content/uploads/2023/12/For-Immediate-Release-PUC-Decision-Slams-Door-on-Rooftop-Solar-HSEA-Press-Release-2.pdf
- Hsbollah, H. M., Hassan, H., & Mohamad, R. (2023). The Impact of Solar Photovoltaic (PV) Adoption on Corporate Image and Business Sustainability in Malaysian Small and Medium Enterprises (SMEs). Journal of Advanced Research in Applied Sciences and Engineering Technology, 31(1), 334-354. https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/article/view/2238/2073
- Imteaz, M. A., & Ahsan, A. (2018). Solar panels: Real efficiencies, potential productions and payback periods for major Australian cities. Sustainable energy technologies and assessments, 25, 119-125. https://www.sciencedirect.com/science/article/pii/S2213138816301291?casa_token=64Ppqf2uQoAAAAA:k08I5yUKl3_GjU7Gcok_jpHo7i6vWvM7WYxwu_BmnKN0GLSSN8BXxxHUI7UlIggRrTJD0Ba4VKQ
- Kang, M. H., & Rohatgi, A. (2016). Quantitative analysis of the levelized cost of electricity of commercial scale photovoltaics systems in the US. Solar Energy Materials and Solar Cells, 154, 71-77. https://www.sciencedirect.com/science/article/pii/S0927024816300824?casa_token=uFVI4QDVyHIAAAAA:PX6lznlaDkcY_h1dKAE28CFj7S2_rCQGXAuRM2JPWHMTkxWk_5lgBisfDO8B9Ww0NcLqPKxpEw
- Kantamneni, A., Winkler, R., Gauchia, L., & Pearce, J. M. (2016). Emerging economic viability of grid defection in a northern climate using solar hybrid systems. Energy Policy, 95, 378-389. https://www.sciencedirect.com/science/article/pii/S0301421516302427?casa_token=UOCK9ZaIAvEAAAAA:C8uPyujGyE8s47R7i-3Xc8uj9BPBUBv8y9zvJU_OKDwvQwKgUnLIePEjcw1nweXv-H3_kHp2
- Kapanadze, K. (2020). A mixed method comparison of students' perception of language use and the reported practice. UAUCU Undergraduate Student Research Exchange Collected Papers 2017. 76-91.
- Lai, C. S., Locatelli, G., Pimm, A., Wu, X., & Lai, L. L. (2021). A review on long-term electrical power system modeling with energy storage. Journal of Cleaner Production, 280, 124298. https://www.sciencedirect.com/science/article/pii/S0959652620343432
- Leewiraphan, C., Ketjoy, N., & Thanarak, P. (2024). An assessment of the economic viability of delivering

solar PV rooftop as a service to strengthen business investment in the residential and commercial sectors. International Journal of Energy Economics and Policy, 14(2), 226-233. https://www.zbw.eu/econis-archiv/bitstream/11159/653374/1/1884022065_0.pdf

- Lund, H., & Mathiesen, B. V. (2009). Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050. Energy, 34(5), 524-531. https://www.sciencedirect.com/science/article/pii/S0360544208000959?casa_token=v0MMTaA6yl4AAAAA:0Otf59W9kkB-IWN2YwEmVlDiOcBGeN-qUQasJ5JIJXn8xn-iyZkmu6xjrB9MNDCVw8clu4J0e
- Manohar, K., Ramkissoon, R., & Adeyanju, A. (2015). Cost benefit analysis of implementing a solar photovoltaic system. International Journal of Innovative Research in Science, Engineering and Technology, 4(12), 1-8. https://www.academia.edu/download/85136076/ijirset.2015.pdf
- McCoy, D., & Lyons, S. (2014). Consumer preferences and the influence of networks in electric vehicle diffusion: An agent-based microsimulation in Ireland. Energy Research & Social Science, 3, 89-101. https://www.sciencedirect.com/science/article/pii/S2214629614000863?casa_token=mpP00ffJ1VgAAAAA:LpZzL5dCTuAO6E70idHQ_4SWPE1MCxQf2VR3zf_bVXHHgPQLGqnSXcCp_OMDfQxEI-_zk3JF
- Ministry of Economic Affairs, Communication and Sustainable Development. (2023) Aruba's Transition to a Sustainable & Inclusive Economic Model. https://www.investinaruba.com/wpcontent/uploads/2023/04/Aruba-National-Action-Plan-2023-2025.pdf
- Ministry of Labor, Integration and Energy. (2020) Energiebeleid. https://www.utilitiesarubanv.com/main/wp-content/uploads/2022/08/Nota-Nationaal-Energiebeleid05-13-2022-114013.pdf
- Mourato, S. (2006). Cost-benefit analysis and the environment. Paris: OECD. https://www.oecd.org/content/dam/oecd/en/publications/reports/2015/12/cost-benefit-analysis-and-the-environment_g17a2732/5jrp6w76tstg-en.pdf
- Ngizwenayo, Z. (2017). Beyond Opinion Polls: Multiple Voices of (Non-)Sovereignty from Aruban People. UAUCU Undergraduate Student Research Exchange Collected Papers 2020. 17-35
- Niekurzak, M., & Kubińska-Jabcoń, E. (2021). Analysis of the return on investment in solar collectors on the example of a household: The case of Poland. Frontiers in Energy Research, 9, 660140. https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2021.660140/full
- N.V. Elmar. (2022, August). Solar Policy "Information about private production of solar energy., 3(5) Retrieved April 2, 2025, from https://www.elmar.aw/sites/default/files/pdf-files/N.V.%20ELMAR%20Solar%20Policy%20English%20Aug%202022%20ver%203.5.pdf
- N.V. Elmar. (2024, November). Rates. Retrieved April 2, 2025, from https://www.elmar.aw/your-electricity-statement/rates
- Oladokun, V. O., & Asemota, O. C. (2015). Unit cost of electricity in Nigeria: A cost model for captive diesel powered generating system. Renewable and Sustainable Energy Reviews, 52, 35-40. https://www.sciencedirect.com/science/article/pii/S1364032115006759?casa_token=q64wYlrKxocAAAAA:55T2tQcOx7_LzcRHOs1s741sT08iKdXjpHgy1B0As75WrYMNxnILxQ_BRuTLvky21gOP5sn1ZQ
- Organización Latinoamericana de Energia. (2025, January). The rise in energy prices in LAC remains below the increase in overall inflation. Retrieved April 2, 2025, from https://www.olade.org/en/noticias/the-rise-in-energy-prices-in-latin-america-and-the-caribbean-remains-below-the-increase-in-overall-inflation/
- Pearce, J. M., Denkenberger, D., & Zielonka, H. (2009). Accelerating applied sustainability by utilizing return on investment for energy conservation measures. International Journal of Energy, Environment and Economics, 17(1), 61. https://www.academia.edu/download/32278533/Return_on_investment_efficien-

cy_journal.pdf
- Peffley, T. B., & Pearce, J. M. (2020). The potential for grid defection of small and medium sized enterprises using solar photovoltaic, battery and generator hybrid systems. Renewable Energy, 148, 193-204. https://www.sciencedirect.com/science/article/pii/S0960148119319111
- Peterson, R. (2020). Over the Caribbean Top: Community Well-Being and Over-Tourism in Small Island Tourism Economies. International Journal of Community Well-Being, 1 - 38. https://doi.org/10.1007/s42413-020-00094-3.
- Pieloor, H. (2022). Barriers and Drivers for Businesses to Adopt Rooftop Solar Power Systems: a qualitative research among businesses with, and without, rooftop-PV (Master's thesis, University of Twente). https://essay.utwente.nl/92563/1/Pieloor_MA_BMS.pdf
- Poullikkas, A. (2013). A comparative assessment of net metering and feed in tariff schemes for residential PV systems. Sustainable Energy Technologies and Assessments, 3, 1-8. https://www.sciencedirect.com/science/article/pii/S2213138813000313?casa_token=7dJY2V74Mn4AAAAA:2C4wy95khNRROdLKLrvwrSeX3OlSCI4bn6A-cw1rFsWvOGQsNo8cr38vn0YraX-LDTNdzNj7R-w
- Prehoda, E., Pearce, J. M., & Schelly, C. (2019). Policies to overcome barriers for renewable energy distributed generation: A Case study of utility structure and regulatory regimes in Michigan. Energies, 12(4), 674. https://www.mdpi.com/1996-1073/12/4/674
- Ram, M., Child, M., Aghahosseini, A., Bogdanov, D., Lohrmann, A., & Breyer, C. (2018). A comparative analysis of electricity generation costs from renewable, fossil fuel and nuclear sources in G20 countries for the period 2015-2030. Journal of Cleaner Production. https://doi.org/10.1016/J.JCLEPRO.2018.07.159.
- Raworth, K. (2018). Doughnut economics: Seven ways to think like a 21st century economist. Chelsea Green Publishing. https://books.google.com/books?hl=hu&lr=&id=bXSrEAAAQBAJ&oi=fnd&pg=PA1&dq=kate+raworth+doughnut+economics&ots=r-PSvZVQS4&sig=1wTHarnxl9mWQpe07FsObjaAv8w#v=onepage&q=kate%20raworth%20doughnut%20economics&f=false
- Rehman, S., Bader, M. A., & Al-Moallem, S. A. (2007). Cost of solar energy generated using PV panels. Renewable and sustainable energy reviews, 11(8), 1843-1857. https://www.sciencedirect.com/science/article/pii/S1364032106000505?casa_token=a85_o-8v8uMAAAAA:j8dkZvmpQDOj1g-GGJRzb_M1JkedR8P_A7r39syHX6zQ15PVrIpz2zS_n9JeY2LYKi81nnwFRMs#aep-section-id23
- RETScreen International. Renewable energy project analysis software. Accessible at http://www.retscreen.net/
- Rio Declaration (1992). Rio Declaration on Environment and Development, in the Report of the United Nations Conference on Environment and Development. UN Doc. A/CONF.151/26 (Vol. 1), 12 August 1992. https://docs.un.org/en/A/CONF.151/26/Rev.1(vol.I)
- Ritchie H. (2021). How have the world's energy sources changed over the last two centuries? Published online at OurWorldinData.org. Retrieved from: https://ourworldindata.org/global-energy-200-years
- Robinson, A. (2024a). Solar PV potential in Aruba by location. ProfieSolar. https://profilesolar.com/countries/AW/
- Robinson, A. (2024b). Solar PV Analysis of Amsterdam, Netherlands. ProfieSolar. https://profilesolar.com/locations/Netherlands/Amsterdam/
- Rodrigues, S., Torabikalaki, R., Faria, F., Cafôfo, N., Chen, X., Ivaki, A. R., ... & Morgado-Dias, F. J. S. E. (2016). Economic feasibility analysis of small scale PV systems in different countries. Solar Energy, 131, 81-95. https://www.sciencedirect.com/science/article/pii/S0038092X16001158?casa_token=tf-GLNCPUqoAAAAA:QkfAkOETwrhZyTuclaEv-iSYEnvyA2n9Ys-

Vr1bK8FOvnmhJwIRlz-8VTOQnbtivkCEvVylRp
- Sandmo, A. (2011). Economics evolving: A history of economic thought. Princeton University Press. https://books.google.com/books?hl=hu&lr=&id=CZEVLXrx5xsC&oi=fnd&pg=PP7&dq=Economics+evolving+:+a+history+of+economic+thought.+Princeton+University+Press.&ots=vQ39XSKEyT&sig=oyUxwIhKIy3pbLM0LKGbilLwiI#v=onepage&q=Economics%20evolving%20%3A%20a%20history%20of%20economic%20thought.%20Princeton%20University%20Press.&f=false
- Scott, J. (2012). What is social network analysis? (p. 114). Bloomsbury Academic. https://library.oapen.org/bitstream/handle/20.500.12657/58730/9781849668200.pdf?sequence=1&isAllowed=y
- Singh, S. J., Huang, T., Nagabhatla, N., Schweizer, P. J., Eckelman, M., Verschuur, J., & Soman, R. (2022). Socio-metabolic risk and tipping points on islands. Environmental Research Letters, 17(6), 065009. https://iopscience.iop.org/article/10.1088/1748-9326/ac6f6c/meta
- Sundaram, A., Gonçalves, J., Ghorbani, A., & Verma, T. (2024). Network dynamics of solar PV adoption: Reconsidering flat tax-credits and influencer seeding for inclusive renewable energy access in Albany county, New York. Energy Research & Social Science, 112, 103518. https://www.sciencedirect.com/science/article/pii/S2214629624001099
- Timmons, D., Harris, J. M., & Roach, B. (2014). The economics of renewable energy. Global Development And Environment Institute, Tufts University, 52, 1-52. https://www.ourenergypolicy.org/wp-content/uploads/2016/02/renewableenergyecon.pdf
- Uddin, K. F., Iqbal, J., & Amjad, S. (2022). Return on investment (ROI) analysis of OFF-Grid solar photovoltaic system in residential sector of Pakistan. Journal of Sustainable Environment, 1(1), 1-16. https://jse.smiu.edu.pk/index.php/jse/article/view/14/7
- Vartiainen, E., Masson, G., Breyer, C., Moser, D., & Medina, E. (2019). Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity. Progress in Photovoltaics: Research and Applications, 28, 439 - 453. https://doi.org/10.1002/pip.3189
- Wampler, M. A. (2011). Cost-Benefit Analysis of installing solar panels on the Schnoor almond ranch. https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1065&context=agbsp
- World Inequality Database. (2025). Top 1% national income share, Aruba, 1980-2023. Retrieved March 31, 2025, from https://wid.world/country/aruba/
- WEB Aruba. (2024). Technologies used. Retrieved on November 15, 2024 from https://webaruba.com/water-xproduction/technologies-used
- WEB Aruba. (2025). Power Production Figures. Retrieved on April 7, 2025 from https://webaruba.com/energy/power-production-figures
- Zhang, R., Lee, M., & Huang, L. (2023). Grid parity analysis of photovoltaic systems considering feed-in tariff and renewable energy certificate schemes in Hong Kong. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2023.113326
- Zhong, J., Bollen, M., & Rönnberg, S. (2021). Towards a 100% renewable energy electricity generation system in Sweden. Renewable Energy, 171, 812-824. https://www.sciencedirect.com/science/article/pii/S0960148121003323?casa_token=HXS4vGCOI1sAAAAA:indAatkJ6mnzMffnPIoprnbJyItPjvHtuheoqWZiSvGrOG6M_9nbBzswdZ8GjuKNe2e_AcbQJRI

Lux (AnneLotte) Grauzinis, University of Aruba

Aruba has been my home for a few years now.

When I came to my first day at the University of Aruba nearly three years ago I couldn't help but be reminded of the eight year old version of me. When she had just had her first diving lesson in the Caribbean sea, she had decided her dreams of becoming a mermaid had been accomplished and decided that from now on the dream was to do something good for the world on an island in the Caribbean. That little girl eventually had to go back home to a much colder Belgium, and would slowly start to forget her dream. I ended up graduating mid pandemic and feeling kind of lost with where the world was, until the University of Aruba, and with that SISSTEM suddenly popped into my view. I will always be grateful for John, who thought I might enjoy this new program that popped up on a small Caribbean island. I don't think he expected how seriously I would take his suggestion. SISSTEM indeed seemed perfect for me, and who better to convince me to make the big move than Eric Mijts. And just like that the little girl with a big dream was back and more excited than ever.

This project served as another reminder of that little girl and how proud she must be. Ever excited to learn something new, this course was another perfect fit. I was able to hear of so many more different experiences and perspectives. I loved seeing the differences in how all of us approached challenges and questions. As a STEM major you sometimes lose sight of the beauty of people, and for me this course served as a reminder of the beauty of our different perspectives. Seeing these students come in and fall in love with Aruba just as I did not too long ago is something I won't easily forget. Seeing how they see and feel passion for things that I never even noticed. How beautiful cultures can be nurtured and should be supported, how people are the drivers for change. I got to see how much I have yet to learn. And that little girl is once again excited to learn of more ways to make the world a better place. And she is even more excited to see how many others are already a positive influence wherever they go.

The Energy Potential of the Aruban Waters

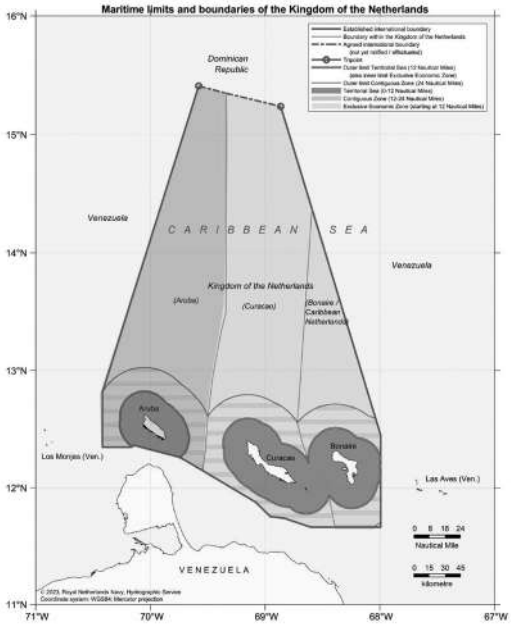
Lux (AnneLotte) Grauzinis

Introduction

Aruba, a small island developing state nestled in the southern Caribbean is now mostly known for its pristine beaches and dramatic rock formations. It has become a place many travel to every year to enjoy. A common challenge for small island communities in the Caribbean is the reliance on those tourists. The island has transformed to accommodate the large amounts of visitors, and as the years go by the island is almost unrecognizable for what it once was. Aruba was once one of the largest players when it came to the oil industry. So critical, in fact, that the Lago oil refinery in San Nicolas was specifically targeted during World War II by German submarines (Bongers, n.d.).

While Aruba's focus has long shifted to the tourism industry as opposed to oil based energy, the island still holds great potential to be a frontrunner among its kind. While usually "being an island" is regarded as a hardship, there is opportunity too, the blue economy. Defined by the World Bank as the "sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem" (PROBLUE: The World Bank's Blue Economy Program, n.d.) the blue economy has great potential for islands such as Aruba, where the ocean not only presents itself as a boundary, but also as a boundless source of renewable energy.

With an exclusive economic zone (EEZ) spanning 25 199 km2 (Marine Regions · Dutch Exclusive Economic Zone (Aruba) (EEZ), n.d.), over 130 times the area of the island itself, Aruba possesses a significant marine space relative to its own size that can be utilized for the diversification of the island's energy mix and possibly even its economy.



(Figure 1: modified from Royal Netherlands Navy, Hydrographic Service Coordinate system: WGS84. (2023). [Mercator projection of Aruba's EEZ])

This report aims to explore the energy potential of the Aruban waters, and to introduce and compare the different methods to capitalize upon this energy potential. The energy generation methods that will be explored and compared in this paper will be Floating Photovoltaics (FPV), offshore wind, wave energy, tidal energy, and Ocean Thermal Energy Conversion (OTEC).

Methodology

The preliminary research presented in this report is obtained through a broad review of existing literature. The selection of literature consists of research papers, reputable online sources, academic journals, government reports, industry publications, and scientific books. The literature review explores multiple aspects of marine energy technologies and their potential application in the Aruban context.

As a part of evaluating the applicability of marine energy technologies for the Aruban context, understanding the potential environmental impacts of these technologies is essential. A small island such as Aruba is in a vulnerable position when it comes to anthropogenic influences (Nature Today & Dutch Caribbean Nature Alliance, 2024). Aruba, in being currently dependent on the tourism industry, is also reliant on the marine environment to remain attractive for tourism. This marine environment can be kept attractive by being kept healthy, especially when it comes to the already vulnerable benthic species which include a wide range of marine flora and fauna (Eicher, 2023). An example of this existing vulnerability is the persisting issue of the stony coral tissue loss disease that has presented itself as a threat since an outbreak in December 2022 (Eicher, 2023). Environmental impacts are an important indicator to assist in deciding where or how a technology can be applied or if a technology is even suitable for the Aruban context.

To understand how the technologies discussed could contribute to Aruba's energy needs, it is also vital to discuss energy production estimates. This report will use these production estimates to compare the amount of space the various technologies need to produce enough energy to meet Aruba's present day average demand of 108 MW (WEB Aruba N.V., n.d.). When it comes to comparing the feasibility of use of marine energy technologies for the Aruban context the cost of energy remains one of the most prioritized factors. This report will use Levelized Cost of Energy (LCOE), a measure for the average cost per megawatt-hour (MWh) over the lifespan of an energy production facility, as a basis for economic comparison between the described technologies. All technologies will also be compared to Aruba's current average energy cost charged to consumers of 257.7$/MWh (Utilities Aruba & Elmar, n.d.).

As with any report reliant on a literature-based methodology, this report is subject to certain limitations. Some especially prominent limitations are the limited availability of region-specific studies, as well as language barriers that may restrict access to relevant sources. In particular, the scarcity of in-depth analyses that are focused on marine energy technologies in the socio-economic and geographical context of Aruba are a prominent limitation throughout this report.

Technologies

Solar Power

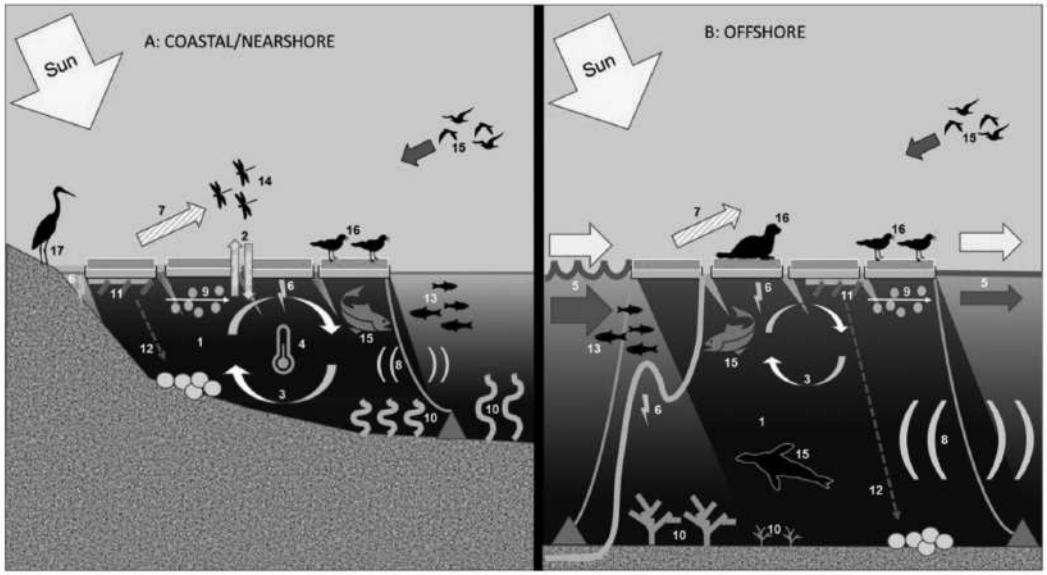
To generate energy using the potential of the ocean, firstly one could simply utilise the sheer amount of surface area available and harness the solar energy. This can be done by using floating arrays of solar panels that are anchored to the seafloor, and connected to land with transmission cables to transmit the energy they generate. One of the biggest limitations of solar energy is the need for large open spaces, something especially difficult for Small Island Developing States (SIDS) due to the limited terrestrial space available.

Using the surface area available on the water surface of Aruba's expansive EEZ instead can offer the opportunity to further capitalize upon the abundance of solar energy available in the region, using floating photovoltaics.

Floating solar installations, also known as floating photovoltaics (FPV), can greatly limit the solar irradiation, the floating structures usually don't let any or very little light through to the water below. While the impact of this limited irradiation would likely depend on the size of the installation, Benjamins et al. (2024) discuss that this shading can have negative impacts on organisms that are reliant on photosynthesis. Notable among affected species would be the group of benthic species, especially corals, that are already negatively affected in Aruba due to anthropogenic activity (Eicher, 2023). Benjamins et al. (2024) also clarify that the effect of this shading is far greater in shallow areas than in deeper waters where it is said to have very little effect on marine life.

Furthermore, these installations can influence hydrodynamics and water-atmosphere exchange. While in smaller scale freshwater installations it is a consideration that the systems reduce evaporation and the general exchange of gases between water and the atmosphere, in marine settings this is deemed as no concern due to the immense size discrepancy between the body of water and the surface area of the installation that would impact the gas exchange (Benjamins et al., 2024).

The mooring of the solar installations could also add to underwater anthropogenic noise pollution. The sounds created when anchor points are constructed as well as the sounds of the mooring lines once attached to the seafloor and the panels are hypothesised to be especially concerning in the case for larger offshore FPV installations in particular during weather events (Benjamins et al., 2024). This human-made underwater noise can affect marine animals that rely on sound for communication or navigation (Benjamins et al., 2024).



(figure 3: Benjamins et al. (2024). Schematic overview of the various potential impacts by FPV on the surrounding environment].

The estimated offshore photovoltaic capacity can vary between 10 and 15 MWp per square kilometre of installation area used (Ghosh, 2023), only 11 square kilometres would be needed to meet Aruba's average daily demand of 108 MW entirely by using floating photovoltaics.

Floating solar power is deemed one of the most affordable large scale marine energy solutions currently available. According to reported estimates, floating photovoltaics have an estimated production cost around 30$ per megawatt-hour for locations with solar incidence angles similar to Aruba (Ghosh, 2023).

Wind Power

Another popular method of generating renewable energy is the use of wind turbines to harness the kinetic energy of the wind. For Aruba, offshore wind energy holds great potential, especially due to its location in the path of the strong and constant Trade Winds. These Trade Winds make Aruba's northern coast a particularly attractive spot for offshore wind turbines. These turbines would usually be constructed using deep support structures anchored in the seabed and, just like FPV, connected to land using transmission cables. By constructing these turbines further offshore within Aruba's Exclusive Economic Zone, it is also possible to avoid common issues associated with land-based wind turbines such as concerns about aesthetics or noise pollution complaints.

Offshore wind farms can have significant environmental impact as, especially during construction, they can cause several environmental changes. The main initial pressures associated with the construction of wind farms are considered to be sediment dispersal as well as acoustic disturbances (Bergström et al., 2014). The construction activities such as drilling or pile-driving into the seabed can stir up sediment. This sediment dispersal will temporarily cloud the water, affecting nearby marine life, especially species that rely on clear water for feeding or breathing. Additionally, construction involves the use of heavy machinery, creating loud anthropogenic noise which again can impact marine animals relying on sound for communication or navigation (Benjamins et al., 2024).

Bergström et al. (2014) also describe how during the operational phase this acoustic disturbance continues, as well as other pressures such as electromagnetic fields, but also effects that they consider to be positive, such as fisheries exclusion, and habitat gain.

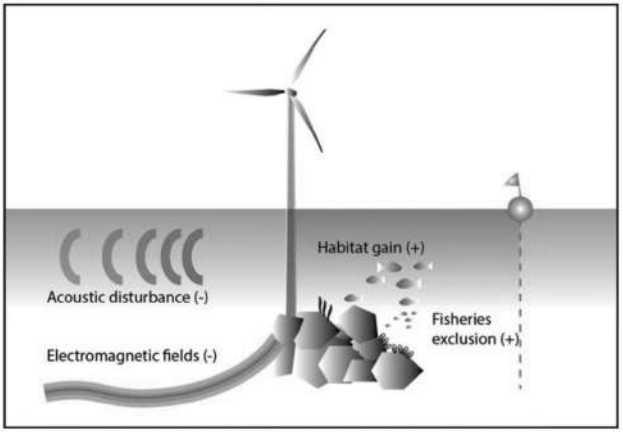


Figure 4: Overview of main pressures from OWF during the operational phase. Expected effect on the local abundance of marine organisms is indicated as (+) aggregation/increase, (−) avoidance/decrease (Bergström et al. 2014).

In figure 4 the positive and negative relationships of these effects are visualised. Gill et al. (2012) explain that while the shielded transmission cables, connecting the turbines to land to connect them to the grid, do not directly emit electromagnetic fields, they are surrounded by magnetic fields that in turn can induce electric fields in the water. When this does happen the electromagnetic field can impact and interfere with the orientation ability for migration as

well as their ability to detect prey or predator for certain fish. While Bergström et al. (2014) explain that generally the effects of the electromagnetic fields are deemed to be low, Gill et al. (2012) also indicate that negative effects can partly be mitigated by adjusting the cable design limiting the electromagnetic fields that are emitted. The acoustic disturbance however remains to have a far greater negative influence on marine life.

Current systems for offshore wind harnessing have a space efficiency of approximately 5 to 10 MW per square kilometre (Bulder et al., 2018). This implies that, similar to offshore solar power generation, an estimated 11 square kilometres would be needed to cover Aruba's own average demand using just offshore wind turbines (WEB Aruba N.V., n.d.).

While the LCOE of offshore wind energy has significantly decreased over recent years, its cost remains higher than that of floating photovoltaics. Offshore wind energy is estimated to have a global average levelized cost of energy of 95$/MWh (NREL et al., 2023). This cost could however still be lowered when the specific positioning and the trade winds are factored into estimations.

Wave Power

Wave energy can be much more effective generating the same amount of energy as a wind farms, using only 5% of the surface area (Slow Mill Sustainable Power BV, n.d.). The kinetic energy of the waves can be harnessed using novice technologies such as linear or point absorbers depicted in figure 2. These structures utilise the constant motion of the ocean waves, this movement holds a lot of kinetic energy especially in areas with constant waves. This makes wave energy an attractive solution considering the island's location in relation to the steady Trade Winds.

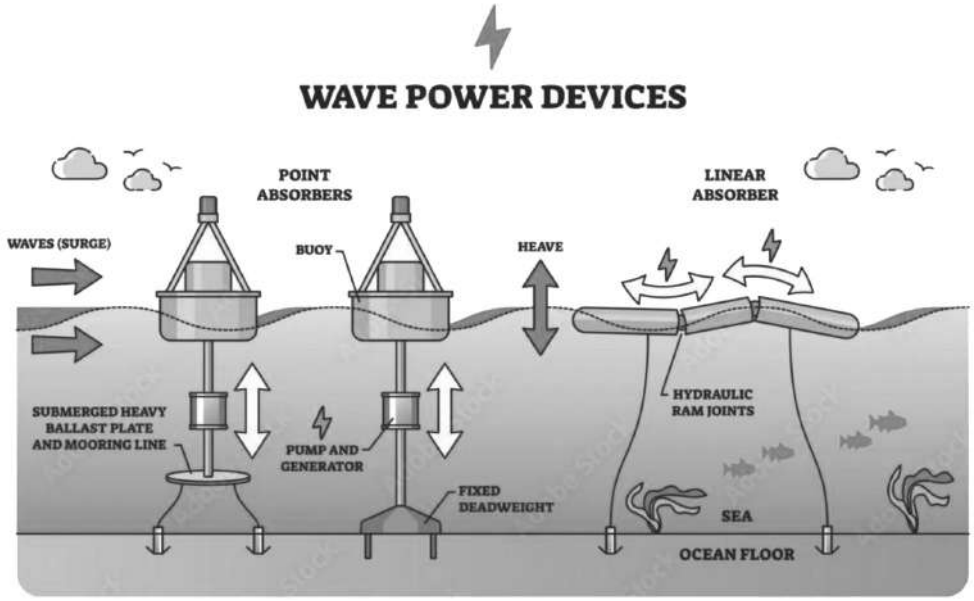


Figure 2: Wave power devices (Vector mine. n.d)

The point absorbers are floating devices that continuously bob up and down following the motion of the waves. As these devices move they drive a generator that converts this motion into electrical energy. Linear absorbers function similarly to the point absorbers while being longer articulated structures that follow the direction of the waves, thus capturing the energy along their length utilizing their hydraulic joints. Both methods would utilise a connection to last using transmission cables. This wave power is promising especially north of Aruba where most of our Exclusive Economic Zone is and where the waves action is stronger due to unsheltered ocean exposed to the trade winds.

The environmental impacts of wave power are largely similar to those of offshore solar power due to the similar ways the two technologies are anchored to the seafloor. While the seafloor disturbances of placing the mooring anchors are seen as temporary, the permanent mooring structures that remain are possibly impactful. That said, research by Akar and Akdoğan (2016) suggests that the impacts of these mooring anchors on the benthic communities are limited when assessed over the long term. A key difference between wave power devices and floating solar panels is that wave energy devices do not shield large areas from solar irradiation, thus having no shading effect.

Despite this, there are mentions of further potential concerns on underwater sounds created by the installation and operation of the wave converters that could interfere with the ability of marine animals to communicate and navigate (Copping et al., 2014). Lastly, similar to the other ocean-based energy systems discussed, the transmission cables used to transport the energy generated can produce electromagnetic fields, possibly impacting certain marine species.

While wave power generation is still in an experimental phase, Veerabhadrappa et al. (2022) show that for Aruba's conditions the potential energy in our waves is an estimated 20 kW/m of coastline. The EEZ area north of Aruba, being more exposed to the trade winds as well as less used for recreational tourism related activities can prove to be an area with great potential for future wave energy development. Though methods generating energy from waves are still relatively new, the technology still poses a promising future as innovation in the field accelerates. The technology still shows great potential currently as just 5.4 kilometers would be needed to meet Aruba's average demand of 108 MW (WEB Aruba N.V., n.d.).
Considering wave power is still a developing area, costs currently remain relatively high. The current levelized cost of energy of pilot projects for wave energy is around 360-690$/MWh(IRENA, 2014). These high costs make it a less attractive option for immediate investment, though continuing innovation in the sector shows future potential.

Tidal Power

Tidal energy attempts to harness the energy in the natural periodic rise and fall of the ocean's tides, which are caused by gravitational forces of the sun and moon (Shetty & Priyam, 2021). As this movement happens reliably every day, this presents to be a very predictable potential source of renewable energy. Historically people used tide mills, often built in the form of a barrage, to trap water at high tide and release it at low tide, turning water wheels to then generate power. However when it comes to the application for the Aruban context, constructing large barrages may not be a viable option due to the small difference between high and low tides in Aruba. Instead, a more practical and modern approach would be to use underwater turbines, similar to wind turbines in function, instead constructed on the seafloor connected to land using transmission cables. These turbines will spin as tidal currents flow past them, converting the kinetic energy of the moving water directly into electrical energy (Shields et al., 2010).

The environmental impacts of tidal technologies will largely depend on the scale and type of device used. While the more historically used tidal barrages can have significant ecological

effects due to their nature of trapping of water, these systems aren't likely suitable for use in the Aruban context. Instead, the turbines that are more likely to be used to harness the energy from tidal streams have a much smaller ecological impact, despite this there are still some environmental considerations. For example, the installation and operation of these turbines can cause disturbances to the seafloor, potentially affecting marine habitats, especially during construction (Shields et al., 2010). The research also indicates that the turbines might also pose a collision risk for marine life, though these effects need to be further investigated to accurately understand how large that risk collision is.

Technologies that harness the kinetic energy of tidal flows have estimated capacities of 5 - 10 MW per square kilometer (Shetty & Priyam, 2021). These capacities show similar promise to solar and wind power, and thus similar to those sources tidal power generation methods would need an estimated 10 to 11 square kilometers to satisfy Aruba's average energy demands (WEB Aruba N.V., n.d.). These estimated figures are based on average tidal flow speeds of 1 to 1.3 m/s the Caribbean region is considered a microtidal region with tidal flow speeds of 0.3 m/s (Expósito-Díaz et al., 2013).

Tidal power, similar to wave power, also remains in its experimental/development phase currently, and the field currently lacks research using the lower tidal flow speeds applicable to the Caribbean region. And its estimated Levelized cost of energy at 380$/MWh makes it a currently less profitable energy generation method to invest in (Bianchi et al., 2024). Based on this, presently, the application of both tidal energy and wave energy are deemed unfeasible in the case of Aruba, unless the application serves the purpose of further advancing the development of these technologies.

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) can serve as a less space intensive marine energy source that takes advantage of the temperature difference between the warmer surface water and colder deep seawater to generate energy (IRENA, 2014). The technology works by pumping up cold water from deep levels of the ocean through large pipes and combining it with warm surface water. This warm surface water is used to evaporate a working fluid, the vapor is passed through a turbine to generate electrical energy. Hereafter the vapor is condensed into liquid again using the colder deep ocean water. Generally needing a temperature difference of 20^0C to function, the Caribbean serves as an ideal region to utilize this energy generation method. In addition to this OTEC has a multifunctionality in addition to generating electricity the cool seawater could also be used to assist in air conditioning systems. Furthermore fresh water is a byproduct of OTEC power production, this can be used to support the water production in Aruba, seeing the island already relies on desalination for its drinking water (IRENA, 2014).

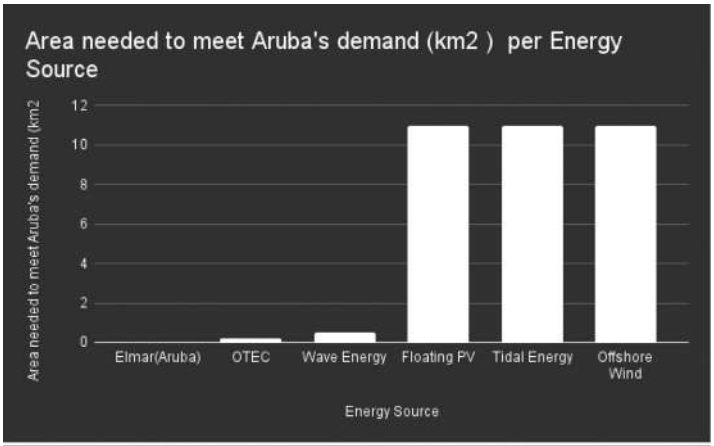
Ocean Thermal Energy Conversion (OTEC) generally has a low environmental impact. The main environmental concern is the potential electromagnetic interference from the transmission cables, though this effect can be minimized by the strategic selection of the location of the plant. Despite its low impact, further research is needed to fully understand the environmental effects of OTEC. For example, NOAA notes that these installations may disrupt the water column as the nutrient-rich water discharged by these systems can affect local marine ecosystems, especially in areas where the surface water is naturally oligotrophic (low in nutrients) (NOAA, n.d.).

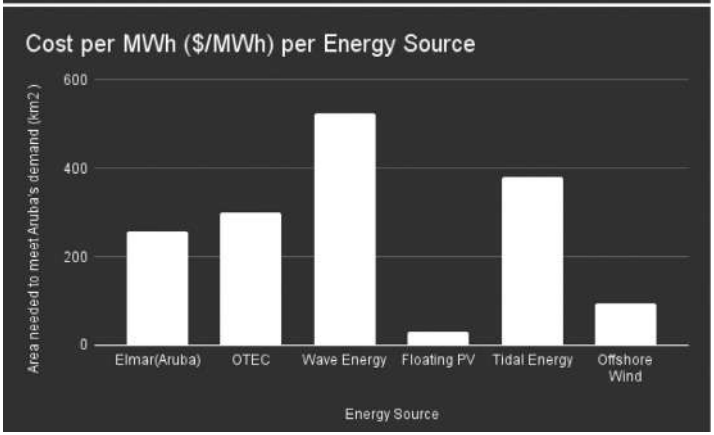
One OTEC plant can have a capacity of between 10 and 100 MW, depending on its design and infrastructure (IRENA, 2014). To meet Aruba's average energy demands fully, a larger scale OTEC plant would be needed matching Aruba's energy demand of 108MW (WEB Aruba N.V., n.d.). Currently no active OTEC plants approach this size as currently much smaller plants are used as pilot projects

to valorize the technology. Using a proposed OTEC plant in Indonesia with a capacity of 100 MW as an example, a required area of 0.01 to 0.02 square kilometres can be found (Adiputra et al., 2019). With a current LCOE of around 300$/MWh this energy generation method can be specifically interesting for island states that often have similar high energy rates already (IRENA, 2014). This cost can be lowered however when using the OTEC as a combination of energy generation and drinkable water purification as well as utilizing larger scale plants. OTEC can be used as a desalination technique resulting in a lowered cost for both water generation as well as energy generation (IRENA, 2014).

Discussion

Comparing Aruba's current average energy cost of 257.7$/MWh (464.5 Afl) as well as Aruba's average demand of 108MW shows interesting comparisons (Utilities Aruba & Elmar, n.d.).





(figure 5: [Marine area needed to meet Aruba's demand per energy source]) (figure 6: [cost per megawatt-hour per energy source])

Comparing these criteria using figure 5 and figure 6 that visualize the data it becomes clear that no single technology dominates greatly when comparing cost and productivity in this context.

From an ecological perspective, wave power, floating photovoltaics, and OTEC tend to be the least environmentally disruptive. It is notable that in the case of OTEC it is made very clear that there is a current lack of data concerning the environmental impacts especially in regards to the discharges. The shading risks of the floating photovoltaics, while impactful, are not a concern when installations are placed further offshore.

In terms of energy generation potential, all discussed energy generation methods are capable of far exceeding Aruba's average energy demands, though the technologies vary significantly in space efficiency. OTEC and wave power stand out as the most space efficient while floating photovoltaics, tidal power, and offshore wind power all require similar area's for reaching Aruba's average demand.

When comparing the LCOE with the other technologies, a different trend emerges. One where floating photovoltaics and offshore wind power stand out greatly as more affordable energy generation methods even compared to the current cost of energy using fossil fuels. While the more experimental energy generation methods remain at higher costs for now it is seen that with more development and future economies of scale these will possibly become more promising solutions.

One energy generation technology does emerge as having more utility than solely generating power, Ocean Thermal Energy Conversion. With the added utility of the byproducts produced, while producing power, this technology appears to be more cost effective than initial estimates show. The integration of energy production with fresh water production and seawater air conditioning, holds great energy savings potential.

Conclusion

This literature review mostly focuses on the practicalities, i.e. the economic interests, of the energy generation potential within the Aruban waters. There are of course many more aspects to be considered. Some of these aspects are import logistics, longevity, maintenance, used materials, carbon footprint, and overall sustainability of the energy generation methods. However, looking at the findings in this literature review, it already becomes clear that Aruba can greatly benefit from investing in ocean-based energy generation techniques. And even when using the least space efficient methods, using less than 0.5% of the Aruban EEZ is required to generate over 10 times the average Aruban demand. The most promising technologies for Aruba appear to be floating photovoltaics, offshore wind power, and OTEC. The documentation on OTEC lacks information, the information that is available shows great potential specifically for the application in SIDS.

Further research will continue to build upon this literature review with more specific data and calculations further examining the import logistics, longevity, maintenance, used materials, carbon footprint, ecological impacts, social acceptance and overall sustainability for the region and Aruba specifically. These calculations will involve more data specific to the Caribbean region as many reports used in this literature review were based on information relevant to different regions, which might lead to inaccurate estimations. An accurate comparison of alternative marine based energy solutions for Aruba will be developed. This with the goal of making realistic predictions and recommendations for Aruba to invest in marine energy.

Aruba has the potential to become a large player in the energy sector again and gain a level of independence from its tourism sector. Aruba could take advantage of its boundary of boundless ocean energy. The island could invest in the blue economy and marine energy to first harness accessible

and affordable energy for its own people, before potentially even becoming a provider for other nearby territories. This could lead to a degree of independence from the tourism industry and to the diversification of Aruba's economy, creating more security for the island and its people.

There is great potential to be found in the deep blue. All we need to do is reach out to it.

References

- Akar, S., & Akdoğan, D. A. (2016). Environmental and economic impacts of wave energy. In Practice, progress, and proficiency in sustainability (pp. 285–309). https://doi.org/10.4018/978-1-5225-0440-5.ch013
- Adiputra, R., Utsunomiya, T., Koto, J., Yasunaga, T., & Ikegami, Y. (2019). Preliminary design of a 100 MW-net ocean thermal energy conversion (OTEC) power plant study case: Mentawai island, Indonesia. Journal of Marine Science and Technology, 25(1), 48–68. https://doi.org/10.1007/s00773-019-00630-7
- Benjamins, S., Williamson, B., Billing, S., Yuan, Z., Collu, M., Fox, C., Hobbs, L., Masden, E. A., Cottier-Cook, E. J., & Wilson, B. (2024). Potential environmental impacts of floating solar photovoltaic systems. Renewable and Sustainable Energy Reviews, 199, 114463. https://doi.org/10.1016/j.rser.2024.114463
- Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Capetillo, N. Å., & Wilhelmsson, D. (2014). Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environmental Research Letters, 9(3), 034012. https://doi.org/10.1088/1748-9326/9/3/034012
- Bianchi, M., Arnal, A., Astorkiza-Andres, M., Clavell-Diaz, J., Marques, A., & Isasa-Sarralde, M. (2024). Life cycle and economic assessment of tidal energy farms in early design phases: Application to a second-generation tidal device. Heliyon, 10(12), e32515. https://doi.org/10.1016/j.heliyon.2024.e32515
- Bongers, E. (n.d.). Historia di Aruba - Lago and Eagle: the oil industry on Aruba. http://www.historiadiaruba.aw/index.php?option=com_content&task=view&id=28&Itemid=42&lang=en
- Bulder, B., Bot, E., & Bedon, G. (2018). Optimal wind farm power density analysis for future offshore wind farms. https://repository.tno.nl/SingleDoc?find=UID%20dfe0ce2f-04fb-4db2-80db-52bc02cfb515

- Copping, A., Battey, H., Brown-Saracino, J., Massaua, M., & Smith, C. (2014). An international assessment of the environmental effects of marine energy development. Ocean & Coastal Management, 99, 3–13. https://doi.org/10.1016/j.ocecoaman.2014.04.002
- Eicher, H. C. (2023). Evaluating coral ecosystem health in Aruba – the development and future of Aruba's coral reefs. https://studenttheses.uu.nl/handle/20.500.12932/45847
- Expósito-Díaz, G., Monreal-Gómez, M. A., Valle-Levinson, A., & Salas-de-León, D. A. (2013). Tidal variations of turbulence at a spring discharging to a tropical estuary. Geophysical Research Letters, 40(5), 898–903. https://doi.org/10.1002/grl.50194
- Ghosh, A. (2023). A comprehensive review of water based PV: Flotavoltaics, under water, offshore & canal top. Ocean Engineering, 281, 115044. https://doi.org/10.1016/j.oceaneng.2023.115044
- Gill, A. B., Bartlett, M., & Thomsen, F. (2012). Potential interactions between diadromous fishes of U.K. conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. Journal of Fish Biology, 81(2), 664–695. https://doi.org/10.1111/j.1095-8649.2012.03374.x
- IRENA. (2014). Wave Energy technology brief. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/Wave-Energy_V4_web.pdf
- IRENA. (2014). Ocean Thermal energy conversion technology brief. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/Ocean_Thermal_Energy_V4_web.pdf
- Marine Regions · Dutch Exclusive Economic Zone (Aruba) (EEZ). (n.d.). https://marineregions.org/gazetteer.php?p=details&id=26519
- Nature Today & Dutch Caribbean Nature Alliance. (2024, October 5). New ecological vegetation map reveals urgent conservation needs for Aruba. naturetoday.com. https://www.naturetoday.com/intl/en/nature-reports/message/?msg=32925
- NOAA. (n.d.). Ocean Thermal Energy Conversion (OTEC) Environmental Impacts. In noaa.gov. https://coast.noaa.gov/data/czm/media/environmentalfactsheet.pdf
- NREL, Stehly, T., Duffy, P., & Hernando, D. M. (2023). 2022 Cost of Wind Energy Review. https://www.nrel.gov/docs/fy24osti/88335.pdf
- PROBLUE: the World Bank's Blue Economy program. (n.d.). World Bank. https://www.worldbank.org/en/programs/problue
- Shetty, C., & Priyam, A. (2021). A review on tidal energy technologies. Materials Today Proceedings, 56, 2774–2779. https://doi.org/10.1016/j.matpr.2021.10.020
- Shields, M. A., Woolf, D. K., Grist, E. P., Kerr, S. A., Jackson, A., Harris, R. E., Bell, M. C., Beharie, R., Want, A., Osalusi, E., Gibb, S. W., & Side, J. (2010). Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. Ocean & Coastal Management, 54(1), 2–9. https://doi.org/10.1016/j.ocecoaman.2010.10.036
- Utilities Aruba & Elmar. (n.d.). Rates. Elmar.aw. https://www.elmar.aw/your-electricity-statement/rates
- Vector Mine. (n.d.). wave power devices. Adobe Stock Photos. https://stock.adobe.com/images/wave-power-devices-for-alternative-electricity-production-outline-diagram-labeled-educational-scheme-with-ocean-tidal-linear-absorber-and-point-absorbers-mechanical-principle-vector-illustration/613717118
- Veerabhadrappa, K., Suhas, B., Mangrulkar, C. K., Kumar, R. S., Mudakappanavar, V., Narahari, N., & Seetharamu, K. (2022). Power Generation Using Ocean Waves: A review. Global Transitions Proceedings, 3(2), 359–370. https://doi.org/10.1016/j.gltp.2022.05.001
- Slow Mill Sustainable Power BV. (n.d.). https://www.slowmill.nl/wave-energy
- WEB Aruba N.V. (n.d.). https://webaruba.com/energy/power-production-figures

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"ipsa scientia potestas est"

-Sir Francis Bacon

Before the start of this course, the interdisciplinary and multidisciplinary context made me curious about what new perspectives I would explore. One key takeaway was that every problem requires different approaches and expertise to be effectively addressed. Learning about the power of language, food security, and the concept of limits to growth has helped me develop a more critical mindset when faced with challenges.

As someone who considers themselves a jack of all trades, I found this course increasingly engaging as it progressed. I was introduced to many new concepts that I had not encountered before, making the learning experience both insightful and enjoyable. The field trips, in particular, deepened my appreciation for the natural and cultural beauty of our surroundings. They also made me realize how little many locals know about Aruba's rich history and the challenges the island faces. This awareness has given me a stronger sense of responsibility, to contribute to a more sustainable future and to spread awareness about these important issues.

Moreover, this course encouraged me to step out of my comfort zone. I explored topics beyond my technical background, delving into socio-economic and cultural dimensions of sustainability. Engaging with the research of my classmates was equally fascinating, as it exposed me to diverse perspectives and innovative approaches to sustainability.

Beyond the academic experience, this course has been incredibly enriching on a personal level.I have had the opportunity to interact with peers from UU/UCU programs each from different backgrounds, each bringing unique perspectives on sustainability. The friendships I have made throughout this course have added an invaluable dimension

to my learning experience. Engaging in discussions, sharing experiences, and working on projects together has strengthened my appreciation for interdisciplinary collaboration and the importance of diverse viewpoints in tackling global challenges.

Overall, this course has deepened my knowledge of sustainability and reinforced the need for interdisciplinary approaches. It has also provided me with lasting friendships and a sense of gratitude for the opportunity to learn from and with others. I look forward to applying these insights in my future studies and professional endeavors.

And last but not least I would like to thank everyone, who in this journey, in one way or another, has shared different perspectives, knowledge, experiences, opinions and viewpoints. These all were filled with knowledge and that to me is the greatest gift one can share with another human being, and to that I am very grateful.

Air to Water Extraction Technology:
Feasibility of different technologies to optimize energy usage for potable water production

Kevin Albert Orozco Mendoza

Introduction

Water is essential for life on Earth, supporting countless species, including humans. However, freshwater scarcity is becoming an increasing global concern due to various anthropogenic factors (Al-Farayedhi et al., 2014). Overexploitation of freshwater resources and pollution have significantly impacted water security, while climate change has further exacerbated the depletion of freshwater supplies (Al-Farayedhi et al., 2014). Furthermore, by 2025 it is estimated that two thirds of the global population will live in regions where water scarcity persists (Gido et al., 2016).

Small Island States (SIS) are particularly vulnerable to water scarcity due to their geographic isolation, limited natural resources, and reliance on external markets. Many SISs depend on groundwater as their primary potable water source; however, excessive extraction depletes these reserves over time (Al-Farayedhi et al., 2014). Given their proximity to the ocean, desalination has become a common alternative, with Seawater Reverse Osmosis (SWRO) being the most widely used method (Gido et al., 2016). Despite its effectiveness, SWRO is highly energy-intensive and relies heavily on fossil fuels, contributing to environmental concerns such as greenhouse gas emissions, and ultimately global warming (Algarni et al., 2017).

In Aruba, drinking water is produced by Water-en Energiebedrijf (WEB) through SWRO, using Heavy Fuel Oil (HFO) as an energy source (WEB Aruba, n.d.). WEB produces approximately 35,600 cubic meters (m^3) of water daily, generating around 105 tons of CO_2 emissions per day or 38,325 tons annually (WEB Aruba, n.d.). Moreover, a 4-person household in Aruba consumes about 21 m3 monthly, which is 0.7 m3 per day (WEB Aruba, n.d.) Compared to the Netherlands, where the daily water usage per capita is 1.43 m^3, and Belgium, where it is 1.5 m^3, Aruba's daily water usage is approximately half that of these larger European countries (Water Use Statistics - Worldometer, n.d.). With emerging technologies that extract water from atmospheric moisture, there is potential for a more sustainable alternative to traditional desalination. If these technologies become more accessible and efficient, they could help reduce Aruba's reliance on fossil fuel-driven water production and lower the island's carbon footprint. By reducing the carbon footprint Aruba will be closer to reaching its Sustainable Development Goals (SDG) by 2030, namely SDG goal 13 climate action (United Nations Statistics Division, n.d.). Therefore, it is increasingly important to innovate and create newer technologies that are more reliable, safe and sustainable for future generations for this island. Some emerging and more sustainable technologies are the harvesting or collecting water from the humidity in the air, which are being studied more in depth.

Air to water generation (AWG) is thought to be a new technology. Nevertheless, it is actually an old technique

used in Middle Eastern countries and in Europe (Algarni et al., 2017). In the 15th century, dew ponds were used to collect water. Later, this method was replaced by fog fences, which harvest water by capturing moisture from the air (Algarni et al., 2017). AWG consists of three different approaches, the first method is adsorption via desiccant or Adsorption Water Extraction from Air (AEWA), the second is condensate collection on cold surface heating called active refrigeration and the third method consists of passive cooling which consists of dew and fog harvesting.

Given Aruba's limited freshwater resources, exploring alternative water sources such as AWG is crucial. Furthermore, these technologies could help reduce water demand, which in turn would lower the carbon footprint associated with water production in Aruba. Therefore, this research paper aims to assess whether Aruba's climatic conditions are suitable for air to water extraction technologies. By addressing the research questions namely, are Aruba's climatic conditions suitable to implement air to water extraction? And, which technologies are best suited for implementation in the Aruban context? Lastly, how can the adoption of these technologies aid in decreasing the carbon footprint in Aruba's water production?

Methodology

This study employed a desk research approach, analyzing existing literature to evaluate the feasibility of air-to-water extraction technology in Aruba. Various sources, including academic journals, research papers, industry reports, government publications, and news articles, were reviewed to gather relevant data. Furthermore, to ensure a comprehensive review, literature was sourced from academic databases such as Google Scholar, ResearchGate, and institutional repositories, using targeted keywords related to air-to-water technology, atmospheric water generation, renewable energy integration, and policy frameworks. Furthermore, generative AI such as ChatGPT was used for grammar correction and text clarity to ensure a comprehensive reading.

The literature review focused on key factors influencing the implementation of air-to-water extraction, such as Aruba's climatic conditions, humidity levels, technological options, energy requirements, and environmental impact. Additionally, case studies from regions with similar climate conditions were examined to assess the practicality of adopting this technology in Aruba. Findings and recommendations were discussed based on the available data, which was used to answer the research question. To make diagrams of potential installations, the app SmartDraw was used.

One of the challenges of this research was the limited availability of literature specific to Aruba. Moreover, since this study relied on assumed calculations, the data was critically reviewed to minimize bias.

Literature Review

Basics of water extraction from air

The theory of water extraction from air does not differ much from the earth's hydrological cycle. The sun plays an important role in the hydrological cycle, as the heat from the sun's radiation evaporates surface water, from lakes, dams, and rivers, as well as the ocean water (Oki & Kanae, 2011). The ocean in turn plays a major role in keeping the earth's temperature at a level where species can thrive (Oki & Kanae, 2011). This evaporation process is the process in which water in liquid form transforms into water into gas form. This form of evaporation amounts to 90% of the total evaporated water (Graham et al., 2009). The remaining 10% consist of the process of evapotranspiration, in which plants take in moisture via their roots and release this moisture as water vapors via the underside of their leaves (Graham et al., 2009). Furthermore, a small amount of water is via

sublimation (Graham et al., 2009). Sublimation is the process where water changes directly from a solid to a gas, this process is common where snow banks shrink due to below freezing temperatures (Graham et al., 2009). After water evaporates it rises to the atmosphere due to its low density (Graham et al., 2009). In high altitudes the air temperatures are low therefore, the water in gas form will condense into liquid water forming clouds (Graham et al., 2009). These clouds will eventually revert this water into the earth's surface as precipitation (Graham et al., 2009). This same principle applies to the extraction of water from air. The condensation of water in gas form is what ultimately can create potable drinking water.

The air that surrounds us is therefore a feasible source to produce drinking water. The potential of extracting water from the atmosphere is promising, and unlike conventional anthropogenic methods, it does not disrupt the local water cycle (Gordeeva et al., 2019). This is particularly relevant in contexts like Aruba, where potable water is produced through seawater desalination using SWRO technology (WEB Aruba, n.d.). However, because this process uses electricity, it is highly energy-intensive and relies on heavy fuel oil (HFO), significantly contributing to Aruba's carbon footprint (WEB Aruba, n.d.). Furthermore, SWRO desalination has several environmental downsides, including the intake of marine organisms, harmful brine discharge with chemical contaminants, high energy consumption and damage to marine ecosystems (Darwish et al., 2012).

Potential of water extraction from air

It is estimated that there is a total of 131,021 liters (L) of water in the earth's atmosphere (Fathieh et al., 2018). This amounts to about 4-15 grams of water per 1m3 of air in arid to semi-arid regions (Gordeeva et al., 2019). Moreover, there is more water vapor present in the atmosphere, compared to liquid water or ice (Schneider et al., 2010). Warm weather makes it easy for air to absorb moisture, thus leading to a high Relative Humidity (RH). To calculate the potential for water extraction in Aruba's land territory, the air volume needs to be determined first. Aruba has a land mass of 179 km2 (Hoetink & Harmannus, 2025). To maximize the water extraction, one could theoretically calculate until about 3 to 4 km where high humidity air starts to decline due to higher altitudes (Makarieva et al., 2013). Therefore, to calculate the volume of air (Va) first, the area (A) needs to be multiplied by the height (h) as illustrated in eq 1.

$$V_a = A * h \qquad eq\ 1.$$

Thus, V_a=179 km^2 * 3 km = 537 km^3, which equals to 5.37 * 10^{11} m^3 of air. The study by Gordeeva et al. (2019) was conducted in a semi-arid location with a yearly mean RH lower than that of Aruba, suggesting that actual water yields could be higher in Aruba's conditions. Their findings show that between 0.004 L and 0.015 L of water can be extracted per cubic meter of air, even in environments with lower RH than Aruba (Gordeeva et al., 2019). In other words, one cubic meter of air has about a minimum of 0,4% to 1,5% of water that can potentially be extracted. Thus, in theory, there can (5.37 * 10^{11}) m^3 * 0.4% = 2,148 * 10^9 m^3 to (5.37 * 10^{11}) m^3 * 1.5% = 8,055 * 10^9 m^3 water in the air as water vapor. Aruba's water demand is 35,600 m^3 per day thus the potential volume of water that can be extracted will be sufficient to satisfy Aruba's water demand (WEB Aruba n.d.).

Analysis of climate suitability for water extraction from atmospheric air

Water content in air is dependent on three parameters, total atmospheric pressure, air temperature and RH (Magrini et al., 2017). In figure 1, these parameters are illustrated at an atmospheric pressure of 101325 Pa, moisture content in g of vapor per kg of dry air (g/kg), temperature in C and percentage of RH (Magrini et al., 2017). For reference

atmospheric pressure in Aruba is 10130.5 Pa and with a fluctuation of 420 Pa daily *(Barometric Pressure in Rooi Santo, n.d.)*. Thus, moisture content is applicable to Aruba at the same temperature and RH. Figure 1 shows that a higher moisture content in air is present in conditions where RH and air temperature are the highest.

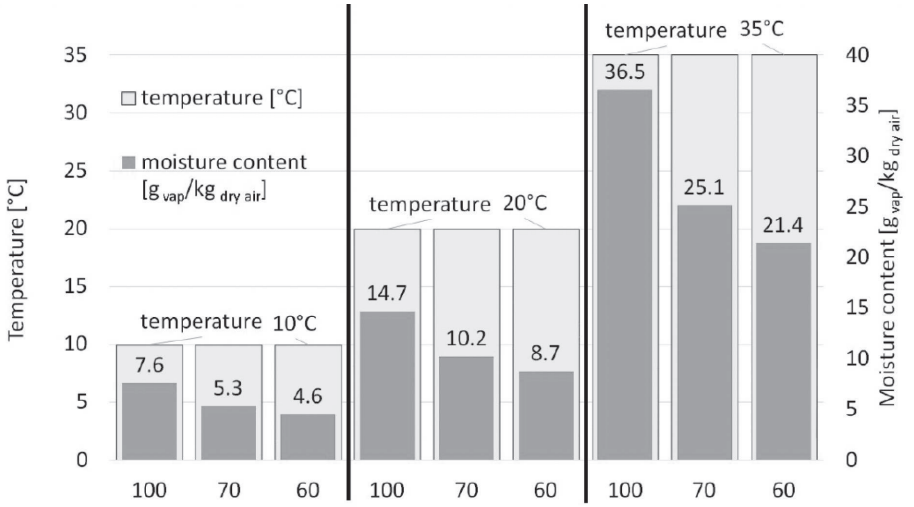

Figure 1 Relationship between moisture content, air temperature and RH (Magrini et al., 2017).

Furthermore, Magrini et al., (2017) highlighted that the water extraction process from atmospheric air requires less energy when the hygrometric degree is high. In other words, the more water vapor content is in the atmospheric air the less energy required to extract water. In the case of Aruba, its high temperature and relative humidity make the air highly hygrometric. Furthermore, the most suitable climate to perform air to water generation is in hot and humid climates. Using data collected by Departamento Meteorologico Aruba from 2020, Aruba's yearly RH is very stable throughout the year with a RH mean of 75.9% (Climate Data Aruba, n.d.). November has the highest RH at 80.9% and March the lowest at 69.9% (Climate Data Aruba, n.d.). Aruba's average temperature has minimal fluctuation throughout the year with the highest at 33.3 C in September and lowest average temperature in January at 24.9 °C (Climate Data Aruba, n.d.). Nighttime temperature has a mean of 25 °C throughout the year (Climate Data Aruba, n.d.). Moreover, Aruba's wind speed averaged to 7.2 meter per second (m/s) per year, with the highest month in May at 9.5 m/s and the lowest in November at 5.2 m/s (Climate Data Aruba, n.d.). Aruba's geographic location results in a climate without distinct seasons and with a reliable source of RH and temperature throughout the entire year (Climate Data Aruba, n.d.).

Technologies

Adsorption Water Extraction from Air (AWEA)

There are numerous technologies to extract water from air and one study done by Gordeeva et al. (2019) utilizes

the AWEA approach utilizing the adsorption-desorption method. In essence, the water vapor is adsorbed by a desiccant from the air during night and extracted during the day by heating the desiccant. This in turn condenses the water vapor into liquid water. This desiccant is a solid adsorbent that extracts the moisture that is present in the air (Gordeeva et al., 2019). These solids are composites that are based on hygroscopic salts and are inserted into a porous solid (Gordeeva et al., 2019). One experiment done by Kumar and Yadav (2015) using calcium chloride (CaCl2) yielded about 180 milliliters per kilogram (mL/kg) of water per day. Furthermore, another study done by Ji et al. (2007) illustrated the potential of using CaCl2 in a patented ultra large pore crystalline material known as MCM-41. The experimental data that Ji et al. (2007) retrieved highlighted that this combination reached 1.75 kg of water per kg of desiccant. This method consists of placing aqueous solution of CaCl2 into MCM-41 (Ji et al., 2007). The solution was first cooled down to ambient temperature under an air proof environment, to prevent unwanted water vapor adsorption (Ji et al., 2007). The MCM-41 porous material was heated to 200 °C and cooled until reaching ambient temperature (Ji et al., 2007). The MCM-41 was then submerged into the aqueous CaCl2 solution, then taken out and washed (Ji et al., 2007). To remove remaining water the MCM-41/CaCl2 adsorbent was dried out in the oven for two hours at 200 °C (Ji et al., 2007). Thereafter, the adsorbent was placed in an adsorption bed to adsorb and desorb water. This method utilizes electricity for heating of the adsorbent. This allows for renewable energy to be used to make the carbon footprint lower. Because the bed is already exposed to the sun, heat can be harnessed by solar radiation. Thus, the electricity demand for heating can be replaced by the aid of solar reflectors that redirect the heat towards the bed. This would ensure a reduction of carbon footprint in the energy usage of this method. Furthermore, the water quality of the extracted water is of drinkable quality (Kumar & Yadav, 2015). The water extracted is odorless, colorless, and slightly hard at 108 mg/L of calcium carbonate (CaCO3) (Kumar & Yadav, 2015).

Active refrigeration

Active refrigeration entails extracting the humidity present in the air, and collecting it as usable domestic water (Raveesh et al., 2021). This process also does not affect the environment, because the water that is removed will be regenerated by the natural water cycle (Raveesh et al., 2021). Furthermore, in cases of catastrophe or natural disasters, where water resources are contaminated, this same technology can be implemented as the process removes the contamination in the air/water (Raveesh et al., 2021). Not only can humidity be converted into usable domestic water, but also fog and water vapor. Water vapor can be transformed in the same way that it happens in the hydrological cycle, which in this case is condensation (Raveesh et al., 2021).

In active refrigeration, atmospheric air is cooled below its dew point (Raveesh et al., 2021). This causes the air to condensate and release water. However, this method requires an external cooling to function (Raveesh et al., 2021). This can be implemented via vapor compression refrigeration (VCR) or thermoelectric cooling (TEC). Moreover, conventional Heating, Ventilation, and Air-Conditioning (HVAC), also can be implemented to recover the water that is produced as a by-product (Raveesh et al., 2021). Active refrigeration is an energy intensive process, therefore if a sustainable operation is desired the cooling in this process can be coupled with renewable energy, such as solar energy and wind energy. Furthermore, the potential of water generation is heavily dependent on climatic conditions, such as RH, atmospheric air temperature, dew point, and atmospheric pressure (Raveesh et al., 2021). This approach of AWG is not adequate for conditions that are low in RH and low temperature. VCR systems are similar to a refrigerator or a household HVAC system (Raveesh et al., 2021).

This system consists of an evaporator section in which air is drawn into via a fan. Thereafter, the air is cooled

below its dew point temperature and then condenses over the evaporator coil, thus extracting water. The extracted water is then collected and could be purified for drinking purposes. The cooling is performed via four key components: the compressor, condenser, evaporator, and expansion valve as seen in figure 2 (Al-Farayedhi et al., 2014). The cooling results in four states of the processed air: vapor, liquid water, saturated air, and dehumidified air. Refrigerant is pumped via a compressor as seen in figure 2. This refrigerant absorbs heat from the evaporator which is exposed to atmospheric warm air and exits as a vapor form, this is the first state (Al-Farayedhi et al., 2014). Afterwards, the evaporator coil is cooled below the dew point of air, this creates a condensation of water vapor where it is then collected (Al-Farayedhi et al., 2014). Furthermore, the refrigerant is then compressed via a compressor to a higher pressure and temperature, this is the second state (Al-Farayedhi et al., 2014). In the third state, the superheated refrigerant in vapor form is cooled in the condenser via air, commonly with an air fan (Al-Farayedhi et al., 2014). This vapor form turns into liquid after cooling. In the fourth and final state, the high-pressure liquid is passed through an expansion valve, where the pressure is dropped and the process repeats (Figure 2, Al-Farayedhi et al., 2014). The main energy consumption in VCR systems is the cooling of the atmospheric air. Furthermore, the warmer the temperature of the atmospheric air, the more refrigeration is needed. Therefore, half of the operation costs of some systems are spent in energy cost (Raveesh et al., 2021). Additionally, this is further exacerbated in drier conditions below a RH of 30% (Salehi et al., 2019). This can be mitigated by the addition of a climatic chamber (figure 2). This chamber will heat up the air, in order to achieve a higher temperature differential which facilitates water condensation. An experiment conducted by Zolfagharkhani et al. (2018) used a mathematical model to calculate the amount of water generated and energy used, yielding results of a Water Generation Ratio (WGR) of 7.9 Liters per day (L/day) and an energy consumption of 1.76-kilowatt hour per liter (kWh/L). The airflow rate was 230 m3 per hour at an ambient temperature of 33 °C and a RH of 24% (Zolfagharkani et al., 2018).

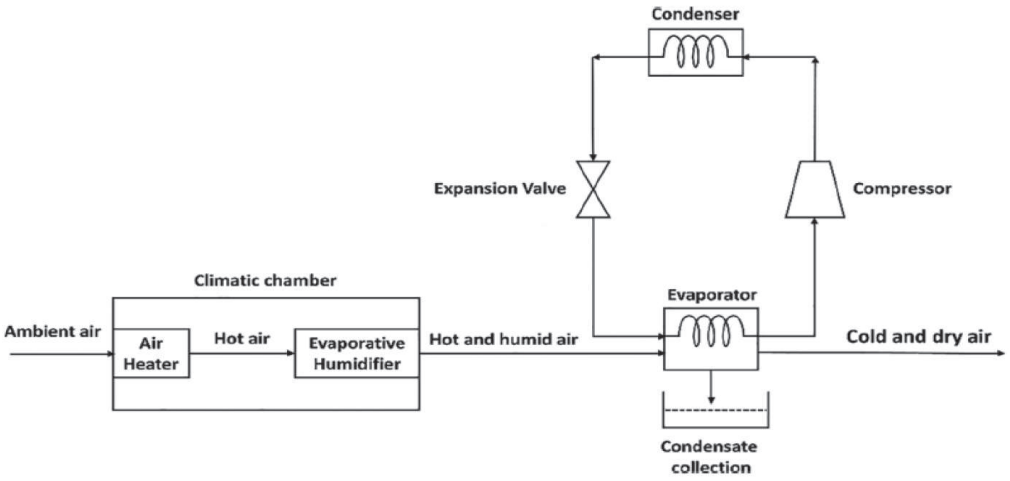

Figure 2 Schematic diagram of a VCR system (Raveesh et al., 2021).

A VCR system that is commonly used in households but that is neglected is the HVAC system used to cool buildings (Raveesh et al., 2021). Water created by these systems has great potential due to the fact that it is an inevitable by-product of building cooling (Raveesh et al., 2021). This water produced, however, needs to be passed through filters before being deemed as safe drinking water. Another limitation with HVAC systems is that they cannot maximize water condensation, as there is a humidity threshold that needs to be within limits for comfort purposes. Magrini et al. (2017) studied HVAC systems in a hotel in Abu Dhabi, with temperatures ranging between 20-30 °C and a RH of 60% (Magrini et al., 2017). This particular system treated 8.33 m3 of air per second (Magrini et al., 2017). This system was especially optimal in summer months, where it managed to collect 10,200 L of water per day, which amounts to 24% of the total hotel's water consumption (Magrini et al., 2017). A study by Al-Farayedhi et al. (2014) found that a single split air conditioning unit with a capacity of 1.5 TR or 18,000 BTU, commonly used for medium sized rooms, could produce and collect 70 L of water per day, or 0.07 m3. A study done by Algarni et al. (2017) further confirmed the efficiency of HVAC water generation by illustrating that 2.25 m3 of water per day was achieved in a 250 m2 office building in September months in Saudi Arabia. Moreover, the minimum water generation achieved daily was 0.62 m3 per day (0.42 kWh/L generated) Climatic conditions of 71 % RH and an ambient temperature of 34 °C, similar to Aruban climatic conditions (Algarni et al., 2017). Water quality of the condensate needs to be monitored for safe consumption (Algarni et al., 2017). HVAC condensate, though similar to distilled water when formed, can become contaminated during collection, transport, and storage (Algarni et al., 2017). Contaminants may include microorganisms, metal ions, and inorganic compounds, picked up from air or contact with system components like pipes and coils. Its slightly acidic nature can cause reactions with metals, potentially leading to toxic buildup over time, especially in irrigation applications. To ensure safety and suitability for reuse, testing and treatment (e.g., chlorine or ozone) is recommended. Properly sized storage tanks are essential to prevent waste, and tanks must meet health standards to avoid microbial risks such as Legionella. Key precautions include avoiding water stagnation and warm temperatures above 45 °C, using safe materials, and performing regular maintenance and leak inspections (Algarni et al., 2017).

TEC transforms electrical energy into a temperature gradient using the Peltier effect (Raveesh et al., 2021). The Peltier effect uses two different layers of ceramic with a cold and hot side (Kadhim et al., 2020). Alongside these ceramic layers, there are different types of semiconductors which are then connected in series (Kadhim et al., 2020). When this system is connected to an electrical source with a Direct Current (DC), the temperature on one side of the device starts to increase, whilst on the other side it decreases (Kadhim et al., 2020). Eventually, the colder side will reach a temperature below the dew point of atmospheric air thus condensing the water vapor in the atmospheric air (Kadhim et al., 2020). This technology is compact, does not require moving parts, does not require refrigerant, operates silently, low maintenance, portable, and environmentally friendly (Raveesh et al., 2021). Notwithstanding, it does have a low coefficient of performance (COP) and low cooling capacity, compared to VCR technologies. However, COP can be optimized with the use of better heating thermoelectric materials and temperature management. An experiment conducted by Kadhim et al. (2020), devices a TEC coupled with a Photovoltaic (PV) module, also known as a solar panel, to produce DC that will operate the system as shown in figure 3. A fan was fitted to the hot side of the TEC system and on the cold side an aluminum cone where condensed water flows into a collector (Kadhim et al., 2020). The system was powered by an 80.54W PV module, and a 12V battery (Kadhim et al., 2020). Furthermore, the RH of the air was around 60% to 80%, and at a temperature of 24 to 31 °C similar to the air conditions in Aruba. Incoming air velocity in this project was between 0.59 m/s and 1 m/s (Kadhim et al., 2020). Moreover, this system performed

more efficiently at a higher airflow (Kadhim et al., 2020). This TEC-AWG system managed to produce 20 mL/h. Moreover, there has been more research conducted on these systems. For example, Eslami et al. (2018) devised mathematical models in order to maximize the efficiency of TEC-AWG. In this research water generation of 26 mL/h was achieved at a temperature of 45 C and a RH of 75% and a consumption of 20 W/Conversely, the mathematical models suggested that at higher temperatures air velocity entering the system should be reduced to achieve optimal COP (Eslami et al., 2018). This is further supported by Irshad et al. (2020), where they state that a decrease in water generation was observed with higher air velocity intake produced by the fan. This is due to the heat transfer from the hot part to the cold part of the TEC system due to high energy consumption, resulting in a performance loss as dissipated heat (Irshad et al., 2020). However, the TEC system in this study was able to generate 820 mL/h at an input of 30 W at an airflow of 0.011 L/s (Irshad et al., 2020). Additionally, the COP of TEC systems can also be improved by implementing different heat sink configurations for heat management (Raveesh et al., 2021). In these systems liquid coolant could be utilized which would allow for a better cooling and heat management, for an optimal COP (Raveesh et al., 2021).

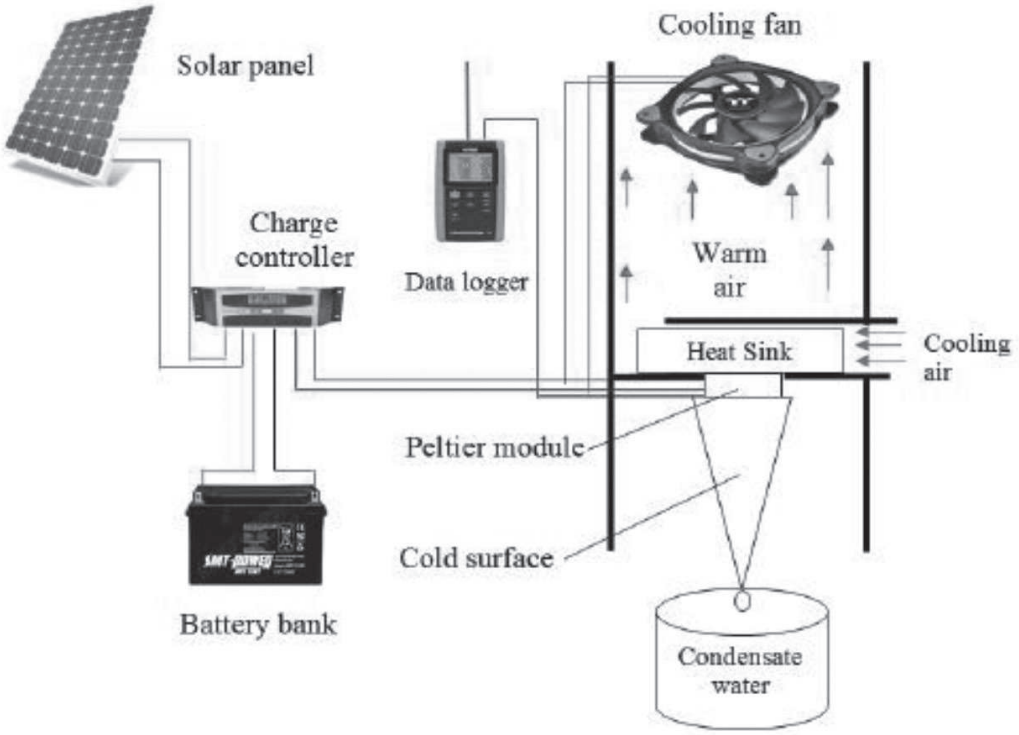

Figure 3 Schematic diagram of a TEC system (Kadhim et al., 2020).

Passive cooling

Passive cooling consists of extracting water vapor from the atmosphere via passive means such as dew and fog harvesting (Raveesh et al., 2021). Dew is the formation of condensates on a surface due to the condensation of water vapor in the atmospheric air (Raveesh et al., 2021). Fog on the other hand, is water droplets formation due to condensation in the atmospheric air (Raveesh et al., 2021). Dew harvesting consists of reaching the dew point of the atmospheric air to allow for condensation on a substrate. This is done via passive radiative cooling which dissipates the heat from a substrate's surface to another body at lower temperature (Vall & Castell, 2017). Conversely, fog harvesting consists of harvesting the water droplets in the atmosphere with mesh-like structures (Raveesh et al., 2021). These structures are engineered in a certain shape to allow for coalescence and ultimately collection by gravity (Raveesh et al., 2021).

Dew formation is dependent on five factors namely, ambient temperature, RH, wind speed, cloud cover, and material properties (Raveesh et al., 2021). The performance of dew formation technology is estimated to yield is rather moderate at 0.8 L/day per m2 of surface with an energy usage of about 25-100 watt per square meter (W/m2) (Raveesh et al., 2016). However, these factors to achieve dew formation naturally can be ignored with the use of radiative cooling. A study done by Chen et al. (2016), devised an apparatus in which it uses the atmospheric transparency window. An atmospheric transparency window is a wavelength in which solar radiation is not absorbed by atmospheric gases (Chen et al., 2016). Meaning that heat on a surface can be redirected by emitting a wavelength of 8-13μm to dissipate heat into the atmosphere. Thus, making it feasible to passively cool a surface to below the dew point by emitting earth's heat into outer space (Chen et al., 2016). This process produces condensate, which can then be collected. The system uses a selective emitter enclosed in a vacuum chamber, designed to be thermally isolated from both sunlight and ambient air. It works by efficiently releasing heat into outer space through the atmospheric transparency window (Chen et al., 2016). In other words, instead of using the Earth as a heat sink like conventional systems, this apparatus uses outer space to dissipate heat. The setup minimizes heat losses using a vacuum of 10^{-6} Torr coupled with multiple reflective shields, and ceramic support pegs (Chen et al., 2016). A zinc selenide (ZnSe) window with anti-reflection coating allows radiative heat transfer while blocking other wavelengths, such as radio waves, and microwaves (Chen et al., 2016). ZnSe is also used to manufacture Light Emitting Diodes (LEDs) (PubChem Compound Summary for CID 4298215, Zinc Selenide (ZnSe)., 2025). Sunlight exposure is reduced using a vertical shade and a mirror-cone. The selective emitter is constructed with layers of silicone nitride (Si_3N_4), silicone (Si), and aluminum (Al), optimized for ideal emissivity within the atmospheric transparency window (Chen et al., 2016). These atmospheric window technologies are being developed with different materials for the emitters (Raveesh et al., 2021). However, a key challenge in this technology is that it requires low solar absorption and a high infrared emission for operations during the day (Raveesh et al., 2021). With the use of nano photonics and metamaterials the efficiency has been improved. These materials consist of hafnium dioxide (HfO2) and silicon dioxide (SiO2) (Fan & Raman, 2018). A temperature reduction of 5°C was possible in the research conducted by Fan & Raman (2018). Furthermore, Chen et al. (2016) was able to achieve a temperature reduction of 42°C. Thus, highlighting the improvements of these technologies. However, these dew collecting methods do function optimally at a RH of 20-40% (Raveesh et al., 2021).

Fog harvesting consists of extracting liquid droplets against a fog capturing device which is a simple net or mesh (Raveesh et al., 2021). This mesh is placed vertically to allow for water collection. One main drawback of this method is that it is limited to geographical locations where the creation of fog is

feasible (Raveesh et al., 2021). Furthermore, the harvesting of fog is possible seasonally (Raveesh et al., 2021). Therefore, this technology requires a favorable topology, higher altitudes and latitudes, and climatic conditions where the presence of fog is plausible. Where this technology has been implemented it has proven to extract between 1.5 and 12 L per m2 per day (L/m2day). Furthermore, in higher altitude countries such as Oman, an extraction rate of 30 L/m2/day has been achieved (Raveesh et al., 2021).

Technical overview of air to water generation technologies

Table 1 provides a comparative overview of the different AWG technologies. Moreover, it summarizes technical parameters, including average water generation rates, energy consumption, optimal RH and temperature for operations. Additionally, it illustrates the potential feasibility of implementing these technologies in an Aruban context.

Technology	Water generation rate	Energy Usage	Optimal RH	Temperature Range	Feasibility in Aruba with a mean temperature of 33 ℃ and RH of 75.9 %
AWEA	180 mL/kg (Kumar & Yadav, 2015), 1.75 L/kg (Ji et al., 2007)	Indirect: heat source or solar reflectors	40-80%	Ambient temperatures of Night and Day, optimal desorption at 200 ℃ differential	Low feasibility, as the availability of desiccants may pose a challenge, and the water yield per kg of desiccant is relatively low
Active refrigeration (VCR)	7.9 L/day (Zolfargharkani et al., 2018);70L/day with HVAC unit (Al-Farayedhi et al., 2014); 0.62-2.25 m^3/day (Algarni et al., 2017)	1.76 kWh/L (Zolfargharkani et al., 2018), 0.42 kWh/L (Algarni et al., 2017)	Best if applied above 30%, optimal range is 60-70%	Typically 24-34 ℃, and above dew point	High feasibility is indicated due to the similarity in relative humidity and temperature conditions
Active refrigeration (TEC)	20-26 mL/h (Kadhim et al., 2020); 820 mL/h (Irshad et al., 2020)	25-100 W/m^2 (Raveesh et al., 2021)	60-80%(Kadhim et al., 2020)	24-31 ℃ (Kadhim et al., 2020)	High feasibility is indicated due to the similarity in relative humidity and temperature conditions however, lower water generation yield than other Active refrigeration technology
Passive cooling (dew harvesting)	0.8 L/m2/day (Raveesh et al., 2021)	25-100 W/m^2 if cooling is enhanced, otherwise no energy consumption	20-40%	The technology is not significantly affected by temperature, provided it stays below the dew point	Low feasibility due to the optimal relative humidity being lower than the current relative humidity in Aruba
Passive cooling (fog harvesting)	1.5-12L/m^2/day and up to 30L/m^2/day in higher altitudes (Raveesh et al., 2021)	No energy consumption as it implements passive cooling	Requires the presence of fog	Cooler temperatures during winter, autumn, or in high-altitude areas	No feasibility due to the absence of fog in Aruba

Table 1 Technical overview of the key parameters on different AWG technologies.

Discussion/Recommendation

Passive cooling technologies like fog harvesting are not suitable for Aruba. Aruba's altitude and latitude does not suit fog formation, thus making it impractical for the implementation of this technology. Dew harvesting could potentially work in Aruba however, it needs space in order to be able to collect water. In order to meet the water demand per person of 0.15 m3 one such apparatus would need to be built 187 times on a larger scale, because it only produces 0.0008 m3 per day per m2. Furthermore, to be able to meet the demand of a four-person household it would need to be built 26250 times bigger. Meaning the surface area where the dew is to be collected would be estimated to around 187 m2 for one person and 26250 m2 for a four-person household. This would cover the surface of a house, for the water demand of one person. With the growing population in Aruba, land space and it carrying capacity are becoming limited (Jurgens et al., 2024). Therefore, the adoption of dew harvesting does not seem suitable for Aruba's context due to its land space requirements.

AEWA technologies do not fare much better in the Aruban context. The land requirement limitation similarly applies to AWEA, because the amount of water generated with this technology is very limited. In order to meet the water household, demand an AWEA technology needs to be made 388 times larger, because the daily demand of 0.07 compared to the actual water generation per day of 0.00018 m3 is 388 times less. Thus, also taking up 388 m2 to be able to produce a useful amount of water. Furthermore, this technology extracts water per kg of desiccant, this would imply that a large amount of this desiccant would need to be imported to Aruba, further contributing to carbon emissions via transport. Another limitation of CaCl2, while environmentally friendly, is that it is very corrosive to metals, such as water piping or metal infrastructure (Vestola et al., n.d.). This makes it unsuitable for the Aruban context that implements metal water piping for water distribution.

TEC is an alternative that holds merit because it is a practical and compact technology that is easily coupled with renewable energy but: Conversely, the main limitation of TEC is the use of ZnSe. ZnSe is known to cause anemia, lethargy, reproductive harm both in men and women, and decrease the level of good cholesterol (PubChem Compound Summary for CID 4298215, Zinc Selenide (ZnSe)., 2025; Ding et al. (2021)). Thus, ZnSe can become a potential health hazard if this element would be dissolved in the collected water. Furthermore, in order to satisfy the water demand for a single person, the most efficient TEC device can only produce 0.624 L or 0.000624 m3 per day. That means to satisfy the daily needs of a single person this device would need to be upscaled 240 times, in either quantity or size. While this is less spatially demanding in comparison to the AWEA technology, this is still insufficient to meet the daily water demand of Aruba However, this device is simple, compact and easily coupled with a renewable energy source such as solar or wind power.

AWG seems to be the most suitable technology for Aruba, as Aruba has suitable climatic conditions for active refrigeration technologies as well as adsorption water extraction from air. Due to Aruba's relatively stable temperatures and RH it makes these technologies reliable for the extraction of water. VCR technology such as HVAC appears to be the most suitable choice. As 80% of Aruban households have at least 1 air conditioning unit (Ruud 2016), there is little need for adopting a new technique or setting up new installations. The condensed water can be purified using water purification filters, repurposing an existing product. Before the condensed water is used as drinking water, quality assessment is needed., Algarini et al (2017) advise implementing ultraviolet (UV) and temperature treatment for the condensate water to be disinfected. Alternatively, the condensed water can be used for non-potable applications such as toilet flushing, dishwashing, laundry, gardening, and other uses that do not require ingestion without the need for disinfection (Hosseinkhani

& Kargari, 2022). Furthermore, if combined with a water pump and filters, this water could be redistributed through the existing household water lines. Moreover, one split unit air conditioner at 1.5 TR or 18,000 btu is able to produce 10% of the daily water needed for an Average Aruban. This 10% is assumed as Al-Farayedhi et al. (2014) stated a plausible water generation of 70 L or 0.07 m3 per day which equals to 10% of the total water demand per household.

If all Aruban households with an air conditioner opted to reuse the water generated instead of discarding it, it would have a positive impact by decreasing the water demand. The total daily water usage of Aruba is 33,000 m3 including hotels, business, and households (Webaruba, n.d.). Hypothetically, the 80% households with air conditioning would amount to 26,400 m3. Furthermore, if these households would re-use the condensate water assuming each household has 4 people and 1 HVAC unit and operation time of 24 hours, it would be a decrease of 10% in water demand. Following the assumption that each household has a 1.5 TR or 18,000 BTU HVAC unit, this would amount to a decrease of 2,640 m3 per day. Meaning that this would amount to a monthly decrease of 79,200 m3, and a yearly decrease of 950,400 m3 (WEB Aruba, n.d.). Water production and carbon emissions are inherently linked, with one directly influencing the other. Therefore, a decrease in water production would mean a decrease in carbon footprint in Aruba's water production. The monthly decrease in carbon emissions would amount to 235 tons of CO2 emissions monthly (WEB Aruba, n.d.) and a yearly decrease of 2,816 tons of CO2 emissions per year (WEB Aruba, n.d.). This is equal to 6,520 of oil barrels consumed yearly (Greenhouse Gas Equivalencies Calculator | Energy and the Environment | US EPA, n.d.).

The energy consumption of an air conditioning system used for water generation is estimated at 29 kWh per day, based on a daily water output of 70 liters. However, since the air conditioner is primarily operated for cooling purposes, its energy usage should not be solely attributed to water production, but merely a repurposing of the by-product of operation.

Ideally, a fully sustainable system would use solar energy to operate. PV modules are small in size and easily transported and installed, compared to windmills (Sagala et al., 2022), making them ideal for potential household installations. Taking inspiration from studies such as Sagala et al. (2022), where water pumps were powered by solar energy, such a device could be implemented for the repurposing of condensate water as seen in Fig 4. The water collected from the HVAC system would be stored in a reservoir tank via waterlines. These water tanks should be exposed to temperatures above 45 °C (using solar energy) to mitigate bacteria and viruses. A water pump would distribute the water which would be powered via a DC battery charged via the PV module and wired through a Solar Charge Controller (SCC) as seen in Fig 4. The SCC main function is to maintain the batteries in the highest state of charge to neither overcharge or undercharge the batteries (Figure 4; Sagala et al., 2022). Moreover, because the pump would run via Alternating Current (AC) a transformer would be needed to transform the DC to AC. Ultimately, the pump would be run via a switch when necessary to distribute water via the existing household water lines. By utilizing renewable energy for the repurposing of water generated by the HVAC system, this system would decrease water demand and reduce carbon emissions.

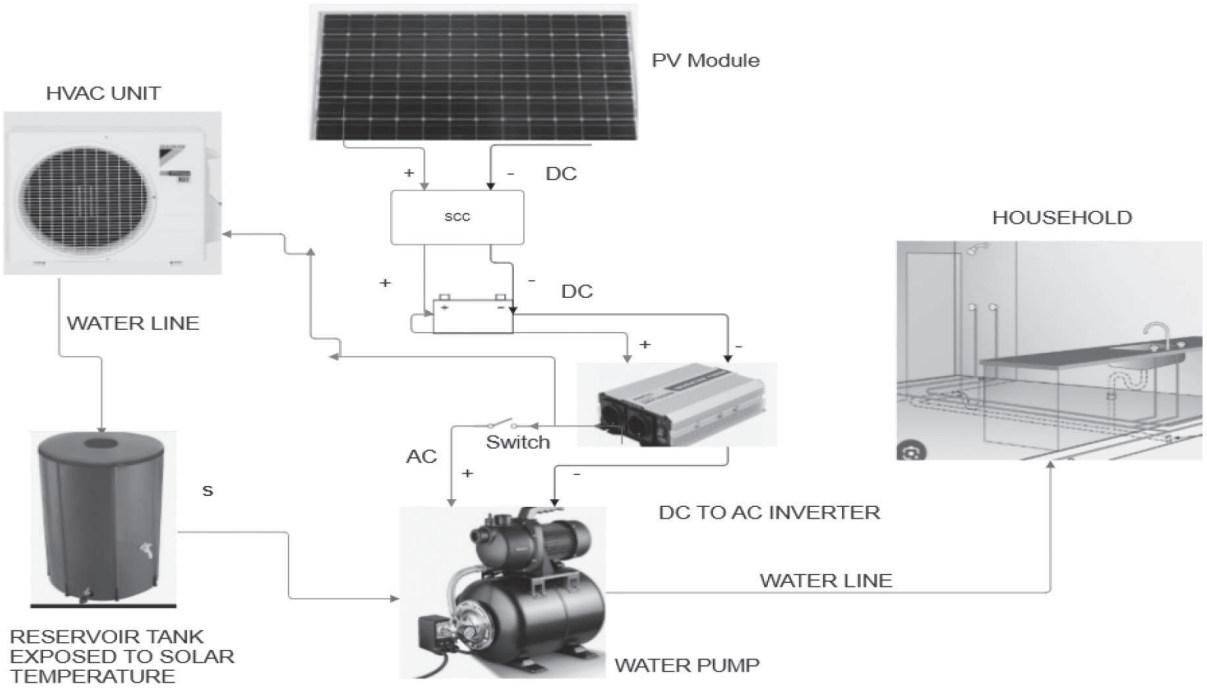

Figure 4 Ideal AWG with repurposing of water using renewable energy.

Conclusion

This research paper assessed the feasibility of air-to-water extraction technologies in Aruba, considering the island's climatic conditions, technological suitability, and potential impact on carbon emissions. Based on the findings, passive cooling methods such as fog harvesting and dew collection are not viable due to Aruba's low altitude, geographic constraints, and extensive land requirements. Additionally, AWEA systems require substantial amounts of imported desiccants, which further contribute to carbon emissions from transportation. Therefore, these technologies are not well suited for large scale water production in Aruba.

Conversely, AWG systems, particularly those utilizing VCR technology, are highly suitable for Aruba. The widespread use of HVAC systems installed in approximately 80% of Aruban households presents an opportunity to repurpose air conditioner condensate water. A single split unit air conditioner at 1.5 TR or 18,000 BTU can generate up to 10% of a 4-person household daily water requirement, demonstrating the potential of this method to supplement Aruba's potable water supply. Although concerns exist

regarding water quality due to metal corrosion, proper filtration, temperatures above 45 °C and purification systems can mitigate this issue, allowing for safe reuse in both potable and non-potable applications. Future studies should aim in assessing the water quality that is generated via HVAC systems.

The implementation of HVAC-based water extraction can significantly contribute to reducing Aruba's dependence on energy-intensive desalination, which is currently powered by HFO. If all households with air conditioners repurposed their condensate water, Aruba could see a 10% reduction in overall water demand, leading to an annual water savings of 950,400 m^3. This reduction would subsequently decrease Aruba's carbon footprint by 2,816 tons of CO_2 per year, equivalent to eliminating the need for 6,520 barrels of oil annually. Furthermore, integrating solar energy into these systems could further enhance sustainability by offsetting the electricity required for HVAC operation.

In conclusion, Aruba's climatic conditions are well suited for AWG via HVAC systems, making this a feasible and sustainable method to supplement water production. By making use of existing infrastructure, implementing proper filtration, and integrating renewable energy, Aruba can decrease both water demand and carbon emissions, moving towards a more resilient and environmentally friendly water production system.

References

- Al-Farayedhi, A. A., Ibrahim, N. I., & Gandhidasan, P. (2014). Condensate as a water source from vapor compression systems in hot and humid regions. Desalination, 349, 60–67. https://doi.org/10.1016/j.desal.2014.05.002
- Algarni, S., Saleel, C., & Mujeebu, M. A. (2017). Air-conditioning condensate recovery and applications—Current developments and challenges ahead. Sustainable Cities and Society, 37, 263–274. https://doi.org/10.1016/j.scs.2017.11.032
- Barometic Pressure in Rooi Santo. (n.d.). barometicpressure.app. Retrieved March 20, 2025, from https://barometricpressure.app/results?lat=12.5861888&lng=-70.0350464
- CALCIUM CHLORIDE. (n.d.). CORE Reader. https://core.ac.uk/download/pdf/24061280.pdf
- Climate data Aruba. (n.d.). meteo.aw. http://www.meteo.aw/climate.php
- Darwish, M., Hassabou, A. H., & Shomar, B. (2012). Using Seawater Reverse Osmosis (SWRO) desalting system for less environmental impacts in Qatar. Desalination, 309, 113–124. https://doi.org/10.1016/j.desal.2012.09.026
- Ding, Y., Yang, Y., Chen, J., Chen, H., Wu, Y., & Jin, L. (2021). Toxic effects of ZnSe/ZnS quantum dots on the reproduction and genotoxiticy of rare minnow (Gobiocypris rarus). Comparative Biochemistry and Physiology Part C Toxicology & Pharmacology, 247, 109065. https://doi.org/10.1016/j.cbpc.2021.109065
- Eslami, M., Tajeddini, F., & Etaati, N. (2018). Thermal analysis and optimization of a system for water harvesting from humid air using thermoelectric coolers. Energy Conversion and Management, 174, 417–429. https://doi.org/10.1016/j.enconman.2018.08.045
- Fan, S., & Raman, A. (2018). Metamaterials for radiative sky cooling. National Science Review, 5(2), 132–133. https://doi.org/10.1093/nsr/nwy012

- Fathieh, F., Kalmutzki, M. J., Kapustin, E. A., Waller, P. J., Yang, J., & Yaghi, O. M. (2018). Practical water production from desert air. Science Advances, 4(6). https://doi.org/10.1126/sciadv.aat3198
- Gido, B., Friedler, E., & Broday, D. M. (2016). Assessment of atmospheric moisture harvesting by direct cooling. Atmospheric Research, 182, 156–162. https://doi.org/10.1016/j.atmosres.2016.07.029
- Gordeeva, L. G., Solovyeva, M. V., Sapienza, A., & Aristov, Y. I. (2019). Potable water extraction from the atmosphere: Potential of MOFs. Renewable Energy, 148, 72–80. https://doi.org/10.1016/j.renene.2019.12.003
- Graham, S., Parkinson, C., & Chahine, M. (2009). The water cycle. Earthobservatory. http://earthobservatory.nasa.gov/Features/Water/printall.php
- Greenhouse Gas Equivalencies Calculator | Energy and the Environment | US EPA. (n.d.). https://19january2017snapshot.epa.gov/energy/greenhouse-gas-equivalencies-calculator_.html
- Hoetink, & Harmannus. (2025, March 20). Aruba | History, Map, flag, population, climate, & Facts. Encyclopedia Britannica. https://www.britannica.com/place/Aruba
- Hosseinkhani, O., & Kargari, A. (2022). Production of high-quality drinking water from chillers and air conditioning units' condensates using UV/GAC/MF/NF hybrid system. Journal of Cleaner Production, 368, 133177. https://doi.org/10.1016/j.jclepro.2022.133177
- Irshad, K., Almalawi, A., Habib, K., Zahir, M. H., Ali, A., Islam, S., & Saha, B. B. (2020). Experimental study of a thermoelectric air duct dehumidification system for tropical climate. Heat Transfer Engineering, 42(13–14), 1159–1171. https://doi.org/10.1080/01457632.2020.1777008
- Ji, J., Wang, R., & Li, L. (2007). New composite adsorbent for solar-driven fresh water production from the atmosphere. Desalination, 212(1–3), 176–182. https://doi.org/10.1016/j.desal.2006.10.008
- Jurgens, S. S., Mijts, E., & Van Rompaey, A. (2024). Are there limits to growth of tourism on the Caribbean islands? Case-study Aruba. Frontiers in Sustainable Tourism, 3. https://doi.org/10.3389/frsut.2024.1292383
- Kadhim, T. J., Abbas, A. K., & Kadhim, H. J. (2020). Experimental study of atmospheric water collection powered by solar energy using the Peltier effect. IOP Conference Series Materials Science and Engineering, 671(1), 012155. https://doi.org/10.1088/1757-899x/671/1/012155
- Kumar, M., & Yadav, A. (2015). Experimental investigation of solar powered water production from atmospheric air by using composite desiccant material "CaCl 2 /saw wood." Desalination, 367, 216–222. https://doi.org/10.1016/j.desal.2015.04.009
- Magrini, A., Cattani, L., Cartesegna, M., & Magnani, L. (2017). Water Production from Air Conditioning Systems: Some Evaluations about a Sustainable Use of Resources. Sustainability, 9(8), 1309. https://doi.org/10.3390/su9081309
- Makarieva, A. M., Gorshkov, V. G., Sheil, D., Nobre, A. D., & Li, B. (2013). Where do winds come from? A new theory on how water vapor condensation influences atmospheric pressure and dynamics. Atmospheric Chemistry and Physics, 13(2), 1039–1056. https://doi.org/10.5194/acp-13-1039-2013
- Oki, T., & Kanae, S. (2011). Global hydrological cycles and world water resources. Sciencemag, 80(10), 862–867. https://ci.nii.ac.jp/naid/10029623049
- Park, K., Kim, P., Grinthal, A., He, N., Fox, D., Weaver, J. C., & Aizenberg, J. (2016). Condensation on slippery asymmetric bumps. Nature, 531(7592), 78–82. https://doi.org/10.1038/nature16956
- PubChem Compound Summary for CID 4298215, Zinc selenide (ZnSe). (2025). National Center for Biotechnology Information. Retrieved March 31, 2025, from https://pubchem.ncbi.nlm.nih.gov/compound/Zinc-selenide-_ZnSe
- Raveesh, G., Goyal, R., & Tyagi, S. (2021). Advances in atmospheric water generation technologies. Energy

Conversion and Management, 239, 114226. https://doi.org/10.1016/j.enconman.2021.114226

- Ruud, D. (2016). Housing and accommodation in recent decades in Aruba. In Spatial Developments in the Aruban Landscape: A Multidisciplinary GIS-based Approach Derived From Geologic, Historic, Economic and Housing Information. Central Bureau of Statistics. Retrieved March 31, 2025, from https://archive.org/download/BNA-DIG-RAPPORT-CBS-LANDSCAPE-2016-LS-05/BNA-DIG-RAPPORT-CBS-LANDSCAPE-2016-LS-05.pdf
- Sagala, A., Tambunan, I., Siagian, P., & Simanjuntak, T. (2020). Implementation of portable off-grid solar water pump for irrigation systems. Jurnal Mantik, 2542–2548. https://www.researchgate.net/publication/358920031_Implementation_of_Portable_Off-Grid_Solar_Water_Pump_for_Irrigation_Systems
- Salehi, A. A., Ghannadi-Maragheh, M., Torab-Mostaedi, M., Torkaman, R., & Asadollahzadeh, M. (2019). A review on the water-energy nexus for drinking water production from humid air. Renewable and Sustainable Energy Reviews, 120, 109627. https://doi.org/10.1016/j.rser.2019.109627
- Schmutz, P. P., Potter, A. E., & Modlin, E. A. (2017). Aruba, Bonaire, and Curaçao. In World geomorphological landscapes (pp. 293–317). https://doi.org/10.1007/978-3-319-55787-8_18
- Schneider, T., O'Gorman, P. A., & Levine, X. J. (2010). WATER VAPOR AND THE DYNAMICS OF CLIMATE CHANGES. Reviews of Geophysics, 48(3). https://doi.org/10.1029/2009rg000302
- Shi, W., Anderson, M. J., Tulkoff, J. B., Kennedy, B. S., & Boreyko, J. B. (2018). Fog Harvesting with Harps. ACS Applied Materials & Interfaces, 10(14), 11979–11986. https://doi.org/10.1021/acsami.7b17488
- United Nations Statistics Division. (n.d.). — SDG indicators. https://unstats.un.org/sdgs/report/2019/goal-13/
- Vall, S., & Castell, A. (2017). Radiative cooling as low-grade energy source: A literature review. Renewable and Sustainable Energy Reviews, 77, 803–820. https://doi.org/10.1016/j.rser.2017.04.010
- Vestola, E., Pohjanne, P., Carpén, L., Kaunisto, T., & Ahlroos, T. (n.d.). Side effects of calcium chloride. TRID. https://trid.trb.org/View/804280
- Water use statistics - Worldometer. (n.d.). Worldometer. https://www.worldometers.info/water/
- WEB Aruba. (n.d.). webaruba.com. Retrieved November 19, 2024, from https://webaruba.com/company/calculate-your-emissions
- Zolfagharkhani, S., Zamen, M., & Shahmardan, M. M. (2018). Thermodynamic analysis and evaluation of a gas compression refrigeration cycle for fresh water production from atmospheric air. Energy Conversion and Management, 170, 97–107. https://doi.org/10.1016/j.enconman.2018.05.016

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There's no agriculture in Aruba, the soils are not great and it barely rains.

Growing up on Aruba, I, like many others, was often told that the island is just too dry for agriculture. We were led to believe that the limited rainfall and poor soil made it virtually impossible to grow anything. Yet, this idea never quite matched up with the stories I learned about in school. We discussed the Arawak Indians who lived on the island long before us, thriving off the land by utilizing whatever natural resources they could find. They relied on what the environment provided, growing crops and foraging, adapting to the challenges of our climate.

In my classes, I also heard about the small plantations that existed during the days of slavery, where families cultivated crops to sustain their livelihoods. These teachings left a lasting impression on me, especially as I enjoyed gatherings with my family, sharing meals that included dishes like "cucumber stoba," made from locally harvested cucumbers and other fresh produce, while recounting stories of how they would help harvest beans from one family's "cunucu" and pick peanuts from another. Thereafter I could go into my yard and pick "grapes", mangos, and cashews from the trees.

These conflicting messages about agriculture sparked my curiosity. I found myself wanting to dig deeper into Aruba's past and present and evaluate the challenges and opportunities we have today. While much of the older "cunucu" land has been transformed into housing developments, erasing traditional practices like rainwater harvesting, the soil is still there waiting for attention, and the rain still falls. We also have this interesting new source of water by capturing condensation from our air conditioning units—water that can be used to support new agricultural efforts. Who knew that our efforts to stay cool would lead to potential water resources?

This journey into exploring local agriculture feels especially important right now, as climate change is making things

much more difficult worldwide. In a time when food often seems to come from plastic packages in grocery stores rather than from the earth, we're losing touch with the value of what we eat. It's disheartening, especially in Aruba, where we rely so heavily on imported food. This realization has motivated me to think seriously about how I can approach water conservation in my daily life while giving agriculture a shot myself. I hope that by trying my hand at growing my own food, and focusing efforts on evaluating water resources, I can inspire others in the community to do the same.

By reconnecting with our agricultural roots and exploring sustainable practices, we can not only enhance our own food security but also bring our community closer to understanding the importance of local production. It's a small step, but I believe that if more of us start planting at home, we can create a ripple effect that leads to a more sustainable and resilient Aruba.

Local Water Management:
Household perspective on the complexities of water harvesting and storage in Aruba

Celia P. P. Kusmus

Aruba, like many small islands, faces significant challenges in water availability due to its semi-arid climate, low rainfall, limited groundwater reserves, and porous calichi soil, which impedes water retention. The island's average temperature is more or less 28°C, along with steady northeast trade winds averaging 7.4 m/s (Departamento Meteorológico Aruba, n.d.). A hydrogeochemical study has shown that the quality of Aruba's groundwater varies from fresh to brackish, due to factors such as seawater intrusion, sea spray, and evapotranspiration (Van Sambeek et al., 2000). As a result, groundwater in the region is often deemed unsuitable for potable use (Van Sambeek et al., 2000).

Despite these natural limitations, Aruba has maintained reliable access to safe drinking water since the installation of its ocean desalination plant in 1932. This facility marked a significant development in the island's water management strategy and has played a critical role in ensuring almost all Aruban households are connected to a potable water supply.

Despite the island's advancements, Aruba remains heavily reliant on desalination, a process that offers both benefits and environmental challenges. While the island does not currently face an immediate threat to its water supply, many Caribbean islands and other Small Island Developing States (SIDS) face pressing concerns of water scarcity.

SIDS are characterized by their small landmasses, isolation, and vulnerability to external shocks, including climate change, economic fluctuations, and inadequate infrastructure. These nations often band together to address shared challenges and influence international policies on sustainable development and environmental conservation. The unique challenges faced by SIDS, such as limited natural resources and reliance on imported goods, exacerbate their vulnerabilities to climate-induced phenomena like rising sea levels and extreme weather events. As these nations work toward sustainable solutions, they must confront issues related to water management, which is critical for both human survival and economic stability. In particular, many SIDS experience significant water scarcity due to factors such as population growth, urbanization, and inadequate infrastructure, which strain available freshwater resources (Forde et al., 2024).

In this context, Aruba's dependence on a single monopoly provider for its water supply poses additional risks to long-term water security. Hence, prioritizing resilience and exploring alternative water sources should be essential components of future planning in Aruba. This includes evaluating the potential for rainwater harvesting, greywater reuse, and investment in sustainable technologies to ensure that the island can sustainably manage its water resources in light of both environmental constraints and the growing demands of its population.

The Impact of Desalination on Water Management

The introduction of desalination has revolutionized Aruba's water security but has also led to significant changes in traditional water management practices. Between 1960 and 2008, household water storage was heavily restricted or outright prohibited, with the construction of rainwater harvesting systems, historically common in Aruba homes, no longer allowed in new constructions. This restriction likely aimed to ensure a consistent market for desalinated water and make the plant financially viable; however, it also resulted in the loss of local knowledge and self-reliant water management practices. This shift has profoundly impacted Aruba, particularly as the population of the island increased from around 55,000 in 1960 to about 98,000 in 2008. (Macrotrends, nd) This growth highlights the disconnect that current generations and newer immigrants have with traditional water storage practices on the island.

Today, while Aruba's desalination plant provides a stable water supply, it has a high carbon footprint due to its reliance on heavy fuel oil for operation. Furthermore, the desalination process generates wastewater (brine) that is discharged into the ocean without filtration, negatively affecting marine ecosystems, including coral reefs (Marchena & Halman, 2018).

Given the global push towards sustainability, it is crucial to explore alternative water sources such as rainwater harvesting, greywater recycling, and wastewater collection from air conditioning units. Although Aruba is often perceived as having low rainfall, calculations show that precipitation exceeds the yearly water production of the Water and Energy Company of Aruba (WEB) by a factor of seven (Montoya Rodríguez, 2024). Unfortunately, much of this rainfall drains directly into the sea, contributing to issues such as soil erosion, nutrient runoff, and urban flooding (Marchena & Halman, 2018).

Some research suggests that rainwater harvesting is the most sustainable method for water supply in small island states (Rahman et al., 2014; Curren & Metzger, 2017). Furthermore, a study by Nel et al. (2017) found that utilizing alternative water sources like rainwater and greywater for non-potable purposes in large properties could reduce municipal water demand by as much as 55% to 69%.

Water and Agriculture in Aruba

A big challenge in Aruba is the decline of local agriculture. Historically, small-scale "cunucus" (farms) played an essential role in sustaining island life by providing fresh produce for local communities. However, industrialization and urbanization have led to the loss of these traditional practices, making it difficult for local farmers to survive or thrive.

For those still engaged in agriculture, access to water remains a significant barrier. The island's water supply is managed by WEB Aruba N.V., the national water and electricity provider. While special agricultural water rates exist, around 5.50 florins per cubic meter, these rates can still present a financial strain for farmers due to the amount of water needed. The disparity in water costs can heavily impact the profitability of agricultural ventures and deter new participants from the farming sector.

Moreover, desalinated water, which farmers often rely on in Aruba, lacks essential nutrients and minerals that are present in freshwater sources, such as groundwater. Groundwater has the advantage of naturally containing vital minerals like calcium, magnesium, and iron, which are crucial for healthy plant growth. In contrast, desalinated water, although potable, often requires the addition of nutrients to support agricultural practices effectively. The absence of these essential components in desalinated water further complicates the cultivation process, potentially leading to lower yields and reduced agricultural viability.

Methods

This study employs qualitative and quantitative research methods to assess water storage practices in Aruba. The research approach includes surveys with locals to understand current water storage practices, challenges, and attitudes toward alternative water sources.

Surveys will consist of structured and semi-structured questions. Additionally, a literature review will be conducted on water storage methods, desalination impacts, and sustainable management. Along with a review of the successful implementation of water harvesting and storage systems on other SIDS. This review will provide a context for understanding the challenges and opportunities related to water storage in Aruba.

Findings from the surveys, and literature review will be analyzed to identify recurring themes and barriers to household water storage. Potential opportunities for improving water storage practices will also be explored, considering environmental, economic, and cultural factors. This mixed-methods approach will provide a more comprehensive understanding of the current state of water storage on a household level in Aruba and inform recommendations for sustainable water management solutions.

Literature Review: Water Availability and Rainwater Harvesting in Aruba

Historical and Cultural Context of Water Use in Aruba

Water availability has always been a critical issue for Aruba due to its semi-arid climate and limited natural freshwater sources. Historically, the indigenous Arawak people relied on surface water and groundwater wells for their supply (Marchena & Halman, 2018). Rainwater harvesting (RWH) was a common practice for collecting fresh water, but as Aruba's economy transitioned from gold and aloe production to oil refining, dependence on industrial-scale water production increased (Derix, 2016). This shift led to the dominance of the Water- en Energiebedrijf Aruba (WEB), which has remained the island's primary source of potable water.

In the 1960s, a law prohibited the construction of rainwater harvesting tanks in new buildings. This fact coincided with a period of population growth and urban expansion, resulting in many homes being constructed without traditional rainwater collection systems (Diaz-Maroto Knöfler, 2024). The restriction was only lifted in 2008; however, many Arubans remain unaware of this change and continue to rely solely on desalinated water (Diaz-Maroto Knöfler, 2024).

Challenges to Rainwater Harvesting Implementation

Despite the legal reinstatement of rainwater collection, implementation remains low. Mukarram et al. (2023) identify financial capacity, lack of technical skills, and insufficient education as primary barriers to the successful adoption of RWH systems. Many Arubans perceive implementation as too complex or labor-intensive, which discourages widespread use.

As well, the misconception that Aruba receives insufficient rainfall persists. Although the island experiences both wet and dry seasons, total annual rainfall is significantly higher than public perception suggests. In fact, rainfall on the island exceeds the annual water production of WEB by a factor of seven (Montoya Rodríguez, 2024). However, nearly all of this water drains into the sea due to a lack of proper collection and retention systems (Marchena & Halman, 2018).

Quality and Composition of Water Sources

Public perception of water quality also affects attitudes toward rainwater harvesting. Many Arubans do not know that desalinated water is at first pure and is only enriched

with a necessary of minerals before distribution (Diaz-Maroto Knöfler, 2024). In contrast, rainwater naturally contains diverse minerals that could be beneficial for non-potable uses. Groundwater, another potential resource, often proves unsuitable for drinking due to its high salinity. A hydrogeochemical study determined that Aruba's groundwater varies from fresh to brackish due to seawater intrusion, sea spray, and evapotranspiration (Van Sambeek et al., 2000). Furthermore, the island's rock substrate inhibits water infiltration, preventing the formation of large groundwater reserves (Derix, 2016b).

Challenges in Water Storage

Water storage presents several challenges in Small Island Developing States (SIDS) like Aruba. These challenges include financial barriers, maintenance issues, lack of knowledge, limited equipment availability, and health risks. Financial Barriers: the cost of installing water storage solutions can be a significant obstacle for many households. The cost of storage tanks and filtration systems varies significantly, with larger and more durable options requiring a substantial financial investment. For example, a local hardware store on Aruba offers limited tank sizes ranging from 120 to 500 liters, with prices fluctuating between 130 and 200 Aruban florins (Kooyman B.V., n.d.). As with many products in Aruba, importing these systems from abroad would further increase costs due to shipping and import fees. As of 2025, the minimum wage in Aruba is around 24,000 AWG per year. With the rising cost of living, many residents prioritize immediate necessities over long-term investments such as water storage. This financial burden makes it increasingly difficult for households to adopt water-saving solutions, even when they could lead to long-term savings.

Maintenance and Upkeep: beyond the initial investment, maintaining a water storage system requires time and effort. Routine maintenance is essential to ensure that stored water remains safe for use. However, several factors hinder proper upkeep, including lack of awareness, accessibility issues, and the unavailability of professional cleaning services. When storage tanks are not regularly cleaned and disinfected, contamination can occur, posing serious health risks (Bacha, 2024).

Knowledge and Awareness: another significant challenge is the general lack of knowledge regarding proper water storage techniques. Various factors influence water quality in storage systems, including the material, color, design, location, and retention time of the tank (Manga et al., 2021). Without proper knowledge and awareness, households may unintentionally compromise water quality, leading to limited usability and potential financial loss.

Limited Equipment Availability: as a small island, Aruba relies heavily on imports for specialized equipment. Access to high-quality storage tanks, filtration systems, and maintenance tools can be challenging. Geographic distance from major markets - as is the case for Aruba - can lead to delays in obtaining necessary equipment or, in some cases, the purchase of inadequate alternatives. If substandard materials are used, households may experience equipment failure, reducing the effectiveness of their storage system and resulting in financial losses.

Health Risks: improperly managed water storage presents significant health hazards. In Aruba, where mosquito-borne illnesses such as dengue fever pose a concern, stagnant water in poorly maintained tanks can become breeding grounds for mosquitoes. Additionally, microbial contamination is another serious risk. Studies have shown that heterotrophic bacterial counts can increase significantly after water has been stored for four to seven days (Evison & Sunna, 2001). Given Aruba's warm climate, the risk of bacterial growth is heightened.

Stored water can also harbor fungi, protozoa, and viruses that pose health risks, even without direct consumption.

Pathogens such as Acanthamoeba spp. and Schistosoma spp., along with viruses like adenoviruses, can lead to infections through skin contact. Furthermore, Legionella spp. poses a risk, particularly when inhaled in misted or aerosolized water. These concerns underscore the importance of proper water management and disinfection protocols to minimize health risks associated with water storage.

Public Perception of Water Costs and Sustainability

Many Arubans perceive their water bills as excessively high, with the average cost for a four-person household reaching approximately 215 Aruban florins per month for 21 cubic meters of water (Web aruba N.V., n.d). Interest in rainwater harvesting as a cost-saving alternative has only recently begun to grow (Diaz-Maroto Knöfler, 2024). The widespread lack of public awareness about the legal allowance and possible financial benefits of rainwater harvesting highlights an urgent need for education and incentives to encourage its adoption.

Furthermore, the current reliance on desalination raises sustainability concerns. The desalination process is energy-intensive and contributes significantly to the island's carbon footprint due to its dependency on heavy fuel oil. Furthermore, the disposal of brine byproducts into the ocean negatively impacts marine ecosystems, including coral reefs (Marchena & Halman, 2018). In the context of climate change and global sustainability initiatives, it is essential for Aruba to explore alternative water management strategies that align with environmental conservation efforts.

Case Studies on Small Island Developing States (SIDS)

Several Small Island Developing States (SIDS) have made significant strides in integrating rainwater harvesting into their national water management strategies, with commendable results. For example, Tonga has successfully added rainwater harvesting into its broader water strategy, promoting the installation of rainwater catchment systems in residential and commercial buildings. This initiative is complemented by educational programs designed to foster awareness about water conservation. These efforts not only facilitate the collection of rainwater but also encourage sustainable water management practices among the population. (Fakhruddin, 2015)

In Fiji, various villages have adopted rainwater harvesting systems as a primary source of drinking water, significantly enhancing local water security. This initiative has been bolstered by support from non-governmental organizations (NGOs) and government programs that encourage the installation of household rainwater tanks. Notably, over 11,400 tanks have been distributed to non-metered areas in Fiji, reflecting a huge commitment to improving water access. Moreover, funds have been allocated to continue developing and expanding this vital initiative, which has proven particularly advantageous for rural communities where access to piped water is limited. (Mala, 2019)

Similar resilience-building initiatives can be observed in Saint Lucia, Grenada, and the Seychelles. In these countries, both government entities and non-profit organizations have facilitated the creation of community cisterns as well as bulk storage systems for rainwater. These systems serve dual purposes by supplying water for household use while also supporting agricultural activities. The implementation of such initiatives not only ensures improved water availability but also enhances the quality of life for residents, particularly for those living on smaller islands with restricted freshwater sources.

In addition to infrastructure development, educational initiatives have been established to instruct residents on efficient water use and the maintenance of rainwater harvesting systems. This combined approach focuses both

on physical infrastructure and community education and has resulted in improvements in water availability and quality. These efforts prove to be crucial in fostering a culture of water conservation, especially in regions facing increased challenges due to limited natural water resources. (Ministry of Agriculture St Lucia, 2022; The Caribbean Environmental Health Institute, 2006; Water Projects, 2020).

Through the case studies that were presented in the previous paragraphs, we can see that the adoption of rainwater harvesting practices, supported by educational initiatives and community involvement, plays a vital role in strengthening the resilience of SIDS against the challenges of water scarcity. By leveraging local resources and fostering sustainable practices, small island nations can pave the way for improved water security and a more sustainable future.

Survey Outcomes on Water Usage and Conservation in Aruba

To better understand local opinions and behaviors around alternative water management in Aruba, a survey was conducted with 32 respondents, focusing on water usage patterns and attitudes toward water conservation. With a sample of 32 people from a population of approximately 108,000, this survey was conducted with a confidence level of 95%, resulting in a margin of error of approximately 18%, which is indicative of the limitations of such a small sample size.

Demographic data from the participants revealed an equal distribution of genders, as well as a diverse representation of household location (refer to Fig 1). The sample showed a balanced age distribution, with an even split between participants below and above the age of 35. All respondents reported utilizing air conditioning units in their homes, and a significant majority (84%) indicated that they do their laundry at home. Furthermore, most participants (80%) reside in standalone houses, a factor that likely influences their water usage patterns.

Notably, over half of those surveyed reported that their monthly water bill was below 100 florins (Fig. 2). It is essential to clarify that this figure relates to household water consumption as a collective metric, rather than reflecting the cost for individuals. Consequently, while around half of the respondents reported bills under this amount, it also suggests that a substantial number, about 50%, may face costs exceeding 100 florins each month. This shows an opportunity for the promotion of water-saving practices among householders on the basis of economic benefit.

Participants expressed a strong willingness to adopt various water conservation practices, revealing significant interest in implementing passive water-saving measures. These measures include the installation of low-flow faucets, the use of efficient appliances, and mindful water use practices, such as turning off the tap while brushing teeth.

While some participants engage in water harvesting, notably through capturing runoff from their air conditioning units, this practice is not widespread across the surveyed group (Fig. 3). This finding underscores the potential for broader adoption of water harvesting efforts in the community. Most methods of water collection primarily involve utilizing buckets and barrels strategically placed at runoff sites. However, participants identify notable challenges that hinder more widespread acceptance, including the prevalence of mosquito infestations and a general lack of knowledge about effective water harvesting practices.

Also, an important point raised during the survey is the presence of "sapo's" (Bufo Marinus toads) on the island, which become more prevalent when water storage is poorly maintained. These toads pose a huge threat to pets such as dogs and cats, as they secrete a toxic substance that can cause serious harm or even death to animals that may come

into contact with them. This factor further complicates the water storage issue, as it adds another layer of concern for residents considering water harvesting.

Most respondents indicate an intention to use collected water primarily for irrigation purposes. This trend highlights the challenges posed by reliance on desalinated water and its shortcomings for agricultural needs. One participant notes the use of harvested water for cleaning outdoor areas and vehicles, showcasing the versatility of non-potable water applications.

The survey also uncovers a large gap in awareness regarding local legislation pertaining to water management. All but three respondents were unaware that the construction of rainwater harvesting systems (regen bakken) has been permitted since 2008. This finding underscores a significant communication vacuum as to changes in legislation, emphasizing the need for improved outreach and education. Despite the fact that most participants are not actively engaged in water harvesting, a noteworthy interest in learning more about these practices is apparent. Participants identify lack of knowledge and awareness as the primary barriers to adoption, closely followed by concerns about health and safety (Fig. 4). Many respondents express support for the introduction of governmental incentives or regulations that would emphasize the importance of water storage, and indicate a desire for enhanced educational resources on the subject.

Moreover, participants raise substantial concerns about potential future water scarcity, with many expressing worries that rising water prices can create additional strain on already tight budgets. The necessity to limit water use to only absolute essentials emerges as a prominent concern, particularly due to its potential impact on human health and hygiene. One respondent emphasizes the critical importance of accessible drinking water on an island like Aruba, where high temperatures and humidity prevail.

Furthermore, participants voice anxieties regarding the emotional well-being associated with water scarcity. One person articulates how stress related to water access, combined with limitations on self-care and hygiene, can negatively affect mental health and quality of life. This insight reinforces the need for holistic approaches to water management that not only address physical water needs but also consider the social and emotional aspects of water scarcity.

Discussion

Based on the results of the survey and the literature review, several key challenges to water harvesting and water storage at the household level have been identified. The most prevalent of these challenges include limited knowledge and awareness, financial limitations, and health concerns. These challenges are often interconnected and can exacerbate one another. For instance, limited knowledge poses obstacles to effective water storage practices, ultimately impacting water quality, use, treatment, and maintenance. This lack of understanding further exacerbates health concerns, as improper storage techniques can lead to contaminated water and diminished health outcomes for people and their pets.

In a similar vein, financial constraints can lead to inadequate storage solutions, which are often compounded by a lack of knowledge about available options and best practices. When households are unable to invest in proper water storage systems or maintenance, they inadvertently contribute to the increase of health risks associated with poor water quality. In Aruba's context, these health risks can manifest in various ways, including the proliferation of vectors such as mosquitoes in stagnant water and the introduction of invasive species like the Bufo Marinus toad, which poses threats to pets via toxic secretions.

The findings from the survey reveal that, while participants express a strong willingness to adopt water conservation

practices and show an interest in implementing passive water-saving measures, significant gaps in knowledge remain. This knowledge gap persists despite the legal opportunity for the reinstatement of rainwater harvesting systems in 2008, which many residents are still unaware of, thereby limiting effective adoption. Therefore, comprehensive educational initiatives that address both water quality and safe storage practices are vital for overcoming these barriers.

Moreover, the emotional and psychological impacts of water scarcity emerged as significant topics from the survey. Participants voice concerns about reliance on desalinated water and its associated costs, which can induce stress and anxiety over water access. Given that many respondents prioritize essential needs, the potential for increased financial burdens related to water prices may lead to wider social implications and affect overall community well-being.

In light of these multifaceted challenges, it is imperative for policymakers to develop and promote supportive regulations and incentives for adopting sustainable water management practices. Public awareness campaigns are essential to encourage community participation and facilitate the understanding of effective water conservation techniques, which, in turn, can help address both physical and emotional aspects of water scarcity.

Future Research

Future research should focus on the evaluation and valorization of water harvesting and storage practices in individual households, particularly in the light of the significant concerns over water pricing and cost of living that emerged during the survey. A comprehensive cost-benefit analysis of various water harvesting methods and storage solutions could provide valuable insights into the economic feasibility of these practices for local residents. By quantifying the potential savings and benefits associated with rainwater harvesting and other alternative water sources, stakeholders may find it easier to promote these practices in the community.

Furthermore, it is essential to conduct an in-depth analysis of how different water sources are utilized. Understanding the specific applications of harvested rainwater such as irrigation, gardening, and non-potable household uses can help identify optimal strategies for managing and maximizing these resources. This knowledge could lead to enhanced practices that not only increase water conservation but also improve resilience against potential water shortages.

In addition to economic considerations, research should explore technological innovations that address the common concerns raised by survey participants and in existing literature. For instance, the development of automated watering systems can significantly enhance efficiency in agricultural practices and landscape management, thereby ensuring that water is used correctly and effectively. Correspondingly, implementing water circulation systems in storage tanks can help prevent stagnation, which often leads to water quality deterioration and pest infestations.

Research into the integration of smart technologies such as sensors and IoT devices, devices embedded with sensors, software and other technologies to share data via the internet, could further optimize the management of harvested water. These technologies can provide real-time monitoring of water levels, quality, and usage patterns, allowing households to make informed decisions about their water management practices.

Addressing these multifaceted dimensions of water harvesting and storage will be crucial for fostering sustainable water management solutions in Aruba. By focusing on both practical applications and technological advancements, future research can play a vital role in

empowering individual households to adopt innovative practices that contribute to the island's water security.

Conclusion

The water management challenges faced in Aruba underscore the urgent need for sustainable practices, innovative solutions, and heightened awareness in response to a changing climate and increasing population pressures. While the island benefits from a relatively dependable desalination plant, reliance on this method raises environmental concerns and adds economic strains on households, making it crucial to explore alternative strategies.

The reinstatement of water storage systems presents a promising opportunity to enhance local water resilience. However, significant barriers, including public awareness, knowledge gaps, and perceptions surrounding water quality, must be addressed to facilitate greater adoption among residents.

This study highlights not only the physical challenges associated with water scarcity but also the emotional and health impacts on the community. As individuals express willingness to engage in water conservation efforts, there is a clear demand for educational initiatives and governmental support aimed at promoting sustainable water management strategies.

Moving forward, Aruba must prioritize a multifaceted approach that includes improving community awareness, exploring alternative water sources, and educating residents about effective water storage practices. Notably, the need for alternative non-potable water sources for irrigation is critical, as desalinated water is often deemed too costly for agricultural use, making household resilience through food production increasingly unfeasible.

The interplay between water management policies, community attitudes, and environmental factors in Aruba presents both challenges and opportunities. By taking advantage of the existing interest among residents to adopt sustainable water practices, and by focusing on enhancing knowledge, financial capabilities, and addressing health concerns, Aruba can move toward a more resilient and sustainable future in water management.

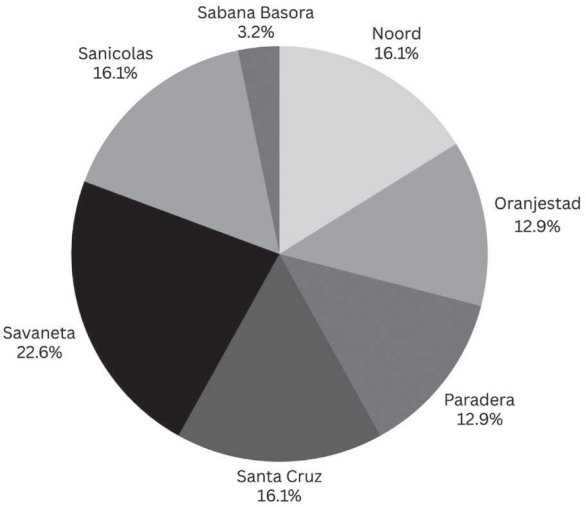

Figure 1. Distribution of the survey participants

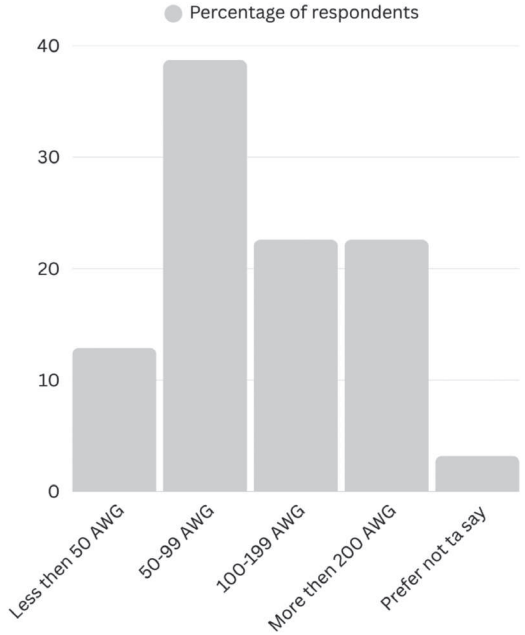

Figure 2. Monthly water cost for survey participantss

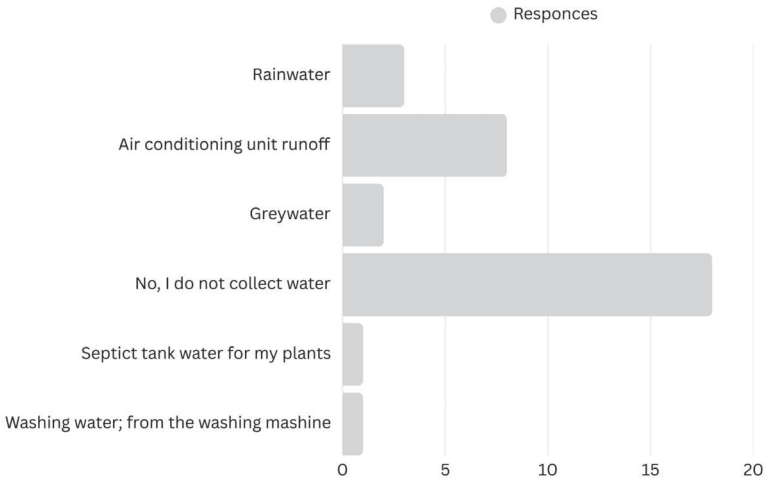

Figure 3. Survey participants currently havesting water

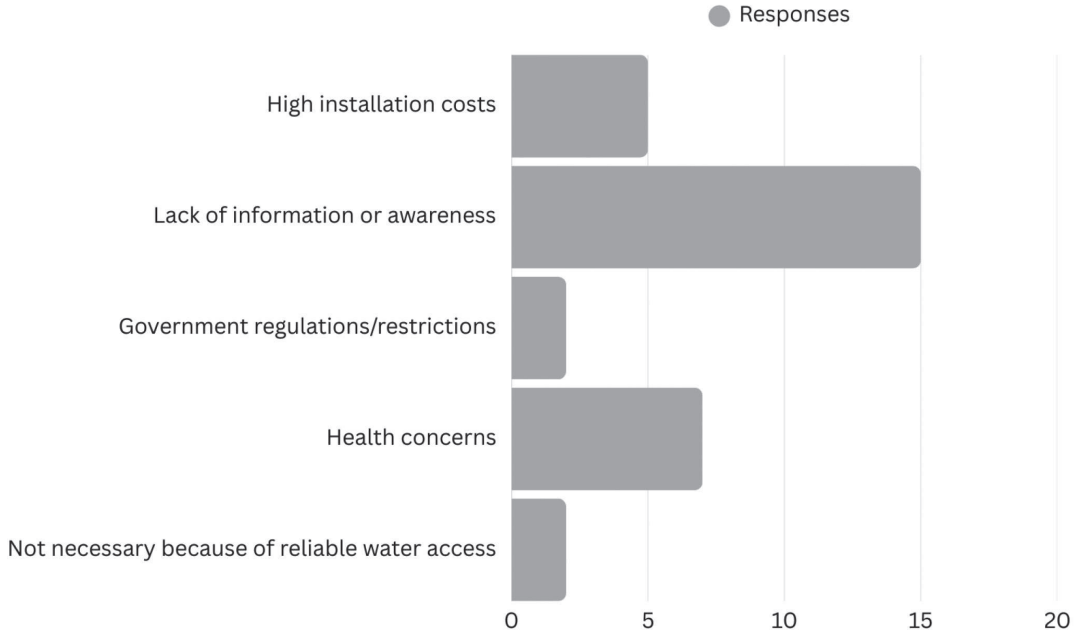

Figure 4. Biggest barriers to water harvesting acording to the survey results.

References

- Aruba population growth rate 1950-2025. MacroTrends. (n.d.). https://www.macrotrends.net/global-metrics/countries/ABW/aruba/population-growth-rate
- Bacha, D. (2024, May 2). The practices and challenges of cleaning and disinfecting water storage tanks in the city of Addis Ababa. Journal of Business and Administrative Studies. https://www.ajol.info/index.php/jbas/article/view/269792
- Curren, R., & Metzger, E. (2017). Living well now and in the future: Why sustainability matters. MIT Press.
- Departamento Meteorológico Aruba (n.d.) Departamento Meteorologico Aruba - Climate Data
- Derix, R. W. M. (2016). The history of resource exploitation in Aruba. Central Bureau of Statistics. https://www.cbs.aw/wp/wp-content/uploads/2016/12/H2_LandscapeSeries_The_History_Of_Resource_Exploitation_In_Aruba_10-10-2016.pdf
- Derix, R. (2016b). Landscape series no.3: A review of Geology, Climate and Hydrology in Aruba. Spatial and Environmental Statistics - Central Bureau of Statistics (CBS Aruba).
- Evison, L., & Sunna, N. (2001). Microbial regrowth in household water storage tanks. Journal AWWA, 93(9), 85–94. https://doi.org/10.1002/j.1551-8833.2001.tb09289.x
- Fakhruddin, Bapon. (2015). Climate Risk Management for Water Sector in Tonga. 10.13140/2.1.2028.3200.
- Forde, M.S., Cashman, A. & Mitchell, K. Sustainability of water resources in Caribbean small island developing states: an overview. Discov Sustain 5, 265 (2024). https://doi.org/10.1007/s43621-024-00478-x
- Ilse Coelman (2024)The efficiency and feasibility of Rainwater harvesting systems in Aruba: An assessment using a multi-criteria analysis, including the preferences of the Aruban community. in Mijts, E. & Ballantyne, J. UAUCU Student Research Exchange Collected Papers 2024.
- Kooyman B.V. Home. Everything You Need to Succeed. (n.d.). https://www.kooymanbv.com/aruba_en/catalogsearch/result/index?q=water%2Btank
- Manga, M., Ngobi, T.G., Okeny, L. et al. The effect of household storage tanks/vessels and user practices on the quality of water: a systematic review of literature. Environ Syst Res 10, 18 (2021). https://doi.org/10.1186/s40068-021-00221-9
- Marchena, F. A., & Halman, J. I. (2018). Aruba's desalination's knowledge and experience: conquering the sea toward desalination's sustainability
- Ministery of Agriculture St Lucia. (2022, November 30). Rain water harvesting - ministry of agriculture. fisheries, food security and rural development. Ministry of Agriculture. Fisheries, Food Security and Rural Development - Eat Fresh... St lucia's best. https://moaslu.govt.lc/rain-water-harvesting/
- Montoya Rodriguez, Y. (2024) The value of rainwater: The economic viability of rainwater harvesting systems in Aruba. In Mijts, E. & Ballantyne, J. UAUCU Student Research Exchange Collected Papers 2024.
- Mukarram, M. M. T., Kafy, A. A., Mukarram, M. M. T., Rukiya, Q. U., Almulhim, A. I., Das, A., ... & Chowdhury, M. A. (2023). Perception of coastal citizens on the prospect of community-based rainwater harvesting system for sustainable water resource management. Resources, Conservation and Recycling, 198, 107196.
- Nel, N., Jacobs, H. E., Loubser, C., & Du Plessis, K.(2017). Supplementary household water sources to augment potable municipal supply in South Africa. Water S.A./Water SA, 43(4), 553. https://doi.org/10.4314/wsa.v43i4.03
- Pratika Mala. (2019, July 11). Over 11,400 water tanks distributed by water authority through rainwater harvesting scheme. https://www.fijivillage.com/news/Over-11400-water-tanks-distributed-by-Water-Authority-through-Rainwater-Harvesting-Scheme-9s2rk5/

- Rahman, S., Khan, M. T. R., Akib, S., Din, N. B. C., Biswas, S. K., & Shirazi, S. M. (2014). Sustainability of rainwater harvesting system in terms of water quality. The Scientific World Journal, 2014. 10.1155/2014/721357
- The Caribbean Environmental Health Institute. (2006, March). National Rainwater Harvesting Programme for Grenada. https://carpha.org/saintlucia/Rain/Rainwater%20Harvesting%20Toolbox/Media/Print/National_RWH_Grenada.pdf
- Van Sambeek, M. H., Eggenkamp, H. G. M., & Vissers, M. J. M. (2000). The groundwater quality of Aruba, Bonaire and Curaçao: a hydrogeochemical study. Netherlands Journal of geosciences, 79(4), 459-466.
- Water projects. SUSTAINABILITY FOR SEYCHELLES (S4S). (2020). http://www.s4seychelles.com/water-projects.html
- Web aruba N.V.: Water- en Energiebedrijf Aruba N.V. WEB Aruba N.V. | Water- en Energiebedrijf Aruba N.V. (n.d.). https://webaruba.com/your-water-bill/high-water-bill
- Yanina Diaz-Maroto Knöfler (2024) An exploratory paper: Societal gaps for a transformation towards sustainable rainwater harvesting in Aruba. In Mijts, E. & Ballantyne, J. UAUCU Student Research Exchange Collected Papers 2024

Raydeline Wever, University of Aruba

A Journey Through SISSTEM.

My SISSTEM journey began when I was just 16, a high school student wandering through a college fair, unsure of what to expect or where my path would lead. Then, amidst the crowd, I noticed a man at the University of Aruba booth, his warm smile instantly puts me at ease. That man was Dr. Eric Mijts, and without knowing it, he would become a defining part of my academic journey.

"Den ki idioma?" he asked, and from that moment, everything felt a little less daunting. I told him about my love for science but admitted I had no idea what to do next. He introduced me to the SISSTEM program, which was set to begin the following year. Suddenly, the uncertainty in my mind settled, and for the first time, I could see a clear path ahead. And my mom was also very happy.

Years later, here I am, reflecting on this incredible chapter of my life, or perhaps just the first part of it. Through SISSTEM and the Academic Foundation Year, I have met some of the most remarkable people. They've given me friendships that transcend age, backgrounds, and perspectives, teaching me more about what it means to be Aruban and how diverse yet united we are in our shared hope for a better future. The road wasn't always easy (trust me on that), but I wouldn't trade this experience for anything. Staying in Aruba, choosing to learn, grow, and advocate for a more sustainable future was one of the best decisions I've ever made.

SISSTEM opened doors to opportunities I never imagined. I became part of the UAUCU program, where I learned from brilliant minds with different cultural and academic backgrounds. It was here that I first started my own research, laying the foundation for my thesis. I also found my passion for environmental advocacy, joining MAGEC and later Synergy, where we work toward a greener, more sustainable Aruba. Beyond that, I took part in projects like

the Surfside Science Project, worked at Plastic Beach Party, experienced the Erasmus+ program in Belgium, and joined the Overseas Countries and Territories Youth Network. And amid it all, I somehow became a pro at cat and house-sitting for my teacher, who knew my skill set would expand to expert feline care? None of this, however, would have been possible had I left my island, and for that, I will always be grateful. These experiences shaped me, prepared me for the unknown, and helped me grow in ways I never expected.

Finally, I want to express my deepest gratitude to everyone who has been part of this journey. To the SISSTEM team, thank you for your guidance and patience. To my family and friends, Abi, Ale, Belle, Andrew, Joel, Marc, Jason, Siguerd, and so many others, you have been with me through every high and low, and I am endlessly grateful.

So, was it worth it?

Yes, yes it was.

Validation of a Low-Cost Hyperspectral Imager for Coral Surveys
A Review of Existing Coral Health Assessment Methodologies

Raydeline Wever

Introduction

"The health of coral reefs has been an issue worldwide for several years, made more prominent by incidences of bleaching", this is the first sentence of the research paper done by Fitt et al in 2000. A quarter of a century later, coral bleaching is still on the rise and the health of corals keeps crashing. Coral reefs are particularly vulnerable to the impacts of climate change, with rising ocean temperatures being a primary stressor (Huisman, 2023). Corals have a symbiotic relationship with algae called zooxanthellae, which live within their tissues and provide them with nutrients through photosynthesis (Hoegh-Guldberg, 1999). Zooxanthellae algae help with the growth of the coral by supplying energy and contributing to the formation of calcium carbonate which are the building blocks of reef structures. Zooxanthellae also produce the pigments that give corals their vibrant colors (Huisman, 2023). However, when exposed to high temperatures, corals experience physiological stress, leading to the expulsion of zooxanthellae, leaving the translucent tissue of the coral exposing the underneath white skeleton, a process called bleaching. Without these algae, corals struggle to meet their energy needs and become more vulnerable and susceptible to diseases, often resulting in mass coral mortality and the degradation and loss of entire reef ecosystems (Brown et al., 1996). In addition to rising ocean temperatures, ocean acidification weakens coral skeletons, reducing their ability to recover from bleaching events (Huisman, 2023). Other human-induced factors, such as coastal development, overfishing, and pollution, further contribute to disturbing coral reefs, exacerbating their decline.

Coral reefs are among the most diverse, productive, and beautiful ecosystems on the planet (Hoegh-Guldberg, 1999). They provide crucial ecosystem services including habitat for a wide range of marine species, supporting local communities and livelihoods through fisheries and tourism, while also acting as natural barriers that protect our shorelines from erosion and storm surges by reducing wave action. They serve as habitats for approximately 25% of all marine species, including fish, crustaceans, and mollusks, making them vital for sustaining ocean biodiversity.

Coral reefs, however, do not exist in isolation since they are closely interconnected with seagrass beds and mangrove forests, forming an ecological triad often referred as the Power of Three (Guannel et al., 2016). They play crucial roles in marine biodiversity, coastal protection, and climate resilience. Seagrasses act as carbon sinks, improve water clarity by trapping sediments, and serve as nurseries for juvenile fishes and invertebrates while mangrove forests function as natural barriers against coastal erosion and provide habitat for marine organisms, many of which later migrate to coral reefs (Carlson et al., 2021). Coral reefs, in turn, support biodiversity and protect coastlines by

attenuating wave energy, preventing erosion of mangroves and seagrass beds. Unfortunately, these valuable ecosystems are under severe pressure and are facing threats from rising climate change, pollution, and anthropogenic activities therefore needing robust monitoring methods to track ecosystem health (Huisman, 2023).

Without healthy coral reefs, coastal communities face increased vulnerability to extreme weather events and economic losses due to the decline of fisheries and tourism. Despite their ecological and economic importance, coral reefs are declining at an unprecedented rate, traditional monitoring methods often detect bleaching too late. Early detection of bleaching events is crucial for implementing timely interventions and improving conservation strategies. Advancing coral health monitoring technology can help mitigate coral loss and support long-term survival of these ecosystems.

Problem Statement

Traditional coral health monitoring methods rely heavily on divers capturing RGB (red, green, and blue) imagery to visually assess the conditions of the coral reefs (Teague et al., 2020). While this method is widely used, it has significant limitations. One major drawback is that RGB imaging lacks spectral resolution and can only detect the bleaching after it has progressed to an advanced stage, typically when 70% or more of the zooxanthellae have already been expelled from the corals. By this point, the damage is already severe, limiting the time available for conservation efforts to respond effectively (Hedley et al., 2016). Additionally, the reliance on human divers makes coral surveys labor-intensive, costly, and subject to environmental constraints such as water clarity and depth (Roche et al., 2016). An alternative approach that has gained attention in recent years is hyperspectral imaging (HSI). Unlike RGB imaging, which only captures only three broad color bands, HSI collects data across hundreds of narrow spectral bands, providing a more detailed and accurate analysis of how light interacts with a subject. The use of spectral data provides a more accurate differentiation between live coral, macroalgae, and other photoactive organisms. In addition, it allows us to assess the health of corals by measuring the intensity of spectral signatures associated with pigments like chlorophyll (Teague et al., 2020; Hedley et al., 2016). This helps to identify if corals are experiencing stress or a decline in their normal health, such as bleaching. However, despite its potential, HSI technology remains expensive and may be inaccessible for widespread coral monitoring, especially for research and conservation purposes in developing regions. A low-cost hyperspectral imager could make this technology more accessible and practical for large-scale coral monitoring, especially in developing regions. The feasibility of such a system, however, needs to be validated. If successful, a low-cost hyperspectral imaging system could provide a powerful new tool for monitoring coral health, supporting conservation efforts, and enabling earlier interventions to protect vulnerable coral reefs.

Research Objective & Limitations

The primary objective of this research is to develop a proof-of-concept for a low-cost hyperspectral imager by adapting existing designs and evaluating their feasibility for coral health monitoring and bleaching detection. This involves reviewing existing methodologies, constructing the imaging hardware, assessing its capability to capture spectral data, and evaluating whether it can detect spectral differences in surrogate samples that mimic coral bleaching conditions.

Limitations include the absence of underwater validation and potential spectral accuracy constraints as in-situ testing is not yet planned. Instead, alternative validation methods will be used, such as using photoactive terrestrial organisms, calcium carbonate samples, and artificially pigmented test samples to explore the simulation of different

spectral differences. Another limitation is that no coding or software integration will be included in this proof-of-concept stage, and it will be solely focused on hardware development. Finally, if needed, local stakeholders may be consulted for the exploration possibilities for custom lenses to improve image quality and performance, however, this aspect remains exploratory, and the final imager may still just rely on off-the-shelf optical components. Despite these limitations, this study provides the foundation for future refinements that could eventually lead to a practical system for early coral bleaching detection.

Literature Review

Traditional Methods for Coral Health Assessment and Their Limitations

Coral reef monitoring has long relied on traditional survey methods that involve in-situ observations, imaging techniques, and remote sensing (Teague et al., 2020). These methods have contributed significantly to understanding coral health but still have some limitations.

1. Diver-based surveys:
Diver-based observations are one of the most common approaches to coral monitoring where trained divers document coral conditions using standardized techniques such as:

- Belt Transects (BT):
  Sampling quadrats along the transect line at predetermined intervals, recording coral health, bleaching, and disease for long-term monitoring.
- Line Intercept Transects (LIT):
  Recording corals directly interacting with the transect line to assess species distribution, population dynamics, and health. Multiple transects are needed for comprehensive data (English et al., 1997).
- Point Count Transects (PCT):
  A random sampling approach where random points along the transect are pre-selected for analysis. It is faster than LIT and often combined with quadrats but requires multiple transects for accurate data in diverse coral environments (Teague et al., 2020).

Even though these are widely used methods for assessing corals they can still have some limitations and drawbacks. Some limitations include:

- Human interpretation can be biased and subjective, leading to variability in data collection therefore requiring highly skilled experts for coral and disease identification (Page et al., 2016).
- Large-scale reef assessments can be time-consuming and labor-intensive. (Hoegh-Guldberg et al., 2007).
- There can be physical limitations like depth, environmental conditions, and visibility, as well as risks like dangerous animals (Teague et al., 2020).

2. Underwater photography & RGB imaging:
Underwater photographic surveys are the primary method for modern reef monitoring, allowing rapid assessment of large areas. A key advantage is that there will be permanent digital records, reducing reliance on field experts and enabling repeat analyses. Some techniques include:

- Quadrat Photography:
  High-resolution digital cameras replace manual counting, improving accuracy and enabling long-term monitoring. Data is analyzed in the lab, reducing diver time underwater.
- Photogrammetry & Structure from Motion (SfM):
  This method uses overlapping images processed through Structure from Motion (SfM) software to create 3D reef models. It can measure reef structure, coral cover, and species distribution (Teague & Scott, 2017). While limited by traditional RGB cameras, it can be enhanced by integrating additional visual data layers.

Some limitations of underwater photography are:

- Limited spectral sensitivity since they are RGB cameras and only capture visible light with a wavelength ranging from 400-700 nm, making it difficult to differentiate between bleached and non-bleached corals before pigment loss is visible (rgb.com, 2025; Baker et al., 2008). Typically, around 50% or more of the total symbiotic algae will be lost before being visible to the human eye (Fitt et al., 2000).
- Images might suffer from color attenuation, low contrast and blurred details due to water conditions (Zhou et al., 2021).

3. Remote sensing:
Remote sensing techniques, like satellite and airborne sensors, make large-scale reef monitoring is more accessible and cost-effective. Satellites such as Landsat, Sentinel-2, and MODIS capture spectral data to track coral bleaching events (Hedley et al., 2016). However, it does have its limitations:

- Incomplete remote sensing coverage may lead to inaccuracies in estimations of the coverage of different benthic types (Foo & Asner, 2019).
- Optical data is affected by depth and turbidity.
- Lack of fine spectral resolution for detailed assessment (Hedley et al., 2016).

4. Remotely operated vehicles (ROVs):
ROVs are unmanned vehicles that could be underwater UUVs, that could replace the human element of underwater surveys decreasing the costs and risks while also improving replicability (Teague et al., 2020). Aerial vehicles (UAV/drones) can also be used as an alternative to satellites as they can provide higher-resolution reef images at lower costs. The drones are equipped with multispectral or RGB cameras that have been used for mapping coral bleaching events and reef damage (Casella et al., 2016). The main issues of unmanned vehicles are battery life and water clarity (Teague et al., 2020). With all the limitations mentioned above, the need for advanced spectral imaging techniques that can provide early-stage coral bleaching detection with higher precision and spectral resolution is emergent. This is where hyperspectral imaging can be an option for a possible alternative solution.

Advances in Hyperspectral Imaging and Its Application in Environmental Monitoring

Hyperspectral Imaging (HSI) is a remote sensing technique that captures and analyzes data across a wide range of the electromagnetic spectrum. Unlike RGB or multispectral imaging, which captures limited spectral bands, HSI collects continuous spectral information across numerous bands, enabling precise material identification based on unique spectral features (Goetz et al., 1985). HSI has been used in various scientific fields, including agriculture, forestry, water resources, and biodiversity monitoring (Shah, 2024; Govender et al., 2007; Clark, 1999). Advancements in hyperspectral sensor technology, data processing, and machine learning techniques have made it more accessible for environmental applications. In the marine environment, hyperspectral imaging has been utilized for detecting and classifying different underwater substrates, such as sand, rock, coral, and seagrass beds. It has been used for mapping seagrass and coral reef health and monitoring harmful algal blooms (Velloth et al., 2015). The ability of HSI to differentiate between live coral, dead coral, and macroalgae is particularly useful for early coral bleaching detection (Hedley et al., 2016). HSI enables more precise assessments by detecting changes in pigments like chlorophyll-a, which degrades before visible bleaching occurs (Holden & LeDrew, 1998). However, traditionally hyperspectral imaging systems are bulky and expensive optical elements, including lenses, spectrometers, and filters (Makarenko et al., 2022). These macroscopic components also do not allow it to process data fast in real-time, and in high-resolution. However,

recent studies show new technological advancements may lead to the miniaturization and cost reduction of hyperspectral sensors, making them more viable for field applications (Hakala et al., 2012; Makarenko et al., 2022; Baston & Qian, 2015; Stuart et al., 2019). Several advancements that can contribute to the minimization of costs and bulkiness include:

- Replacement of bulky and expensive optical elements with metasurfaces:
  The metasurfaces in the Hyplex system are designed using artificial intelligence and are compatible with CMOS sensors (Makarenko et al., 2022). The CMOS is an acronym for Complementary Metal Oxide Semiconductor image sensors that convert light into electrical signals (global.canon, 2025).
- Use conventional monochrome cameras:
  Hyplex utilizes standard monochrome cameras instead of specialized and expensive spectrometers (Makarenko et al., 2022).
- On-chip computational hyperspectral imaging:
  Broadband filtering materials are integrated directly into the imaging sensor, which allows data cubes with full spatial and temporal resolution to be captured (Baston & Qian, 2015). This simplifies the optical design by eliminating the need for external filters and enhances light throughput.
- Integrated design for LiDAR:
  The design aims to combine active hyperspectral imaging and laser scanning into the same instrument (Hakala et al., 2012).

These are some of the advancements, however, future research should still aim to refine cost-effective hyperspectral imagers by improving spectral resolution while maintaining affordability. Innovations in custom lens manufacturing and filter design may also enhance the feasibility of low-cost hyperspectral solutions for marine applications.

Research Gaps

Despite advancements in hyperspectral imaging and low-cost sensor technologies, several research gaps remain in this research:

- Affordability and accessibility:
  Most hyperspectral imaging systems remain too expensive for widespread use in coral reef monitoring. This research investigates a cost-effective imager design that can be replicated by researchers in resource-limited settings.
- Validation of low-cost hyperspectral imaging for coral health assessment:
  While HSI has been successfully applied to agriculture, water quality monitoring, and forestry, there is limited research on the performance of low-cost hyperspectral imagers in coral reef environments. This study evaluates the feasibility of a low-cost alternative for early-stage bleaching detection.
- Simulation of spectral data collection on land:
  Given the logistical challenges of in-situ testing in marine environments, this research explores land-based experimental setups that can effectively simulate coral spectral properties.

Methodology

Research Design

This study follows a proof-of-concept framework, where the main goal is to assess the feasibility of building an affordable and effective hyperspectral imaging system for early coral health assessment. The research methodology consists of a four-phase approach:

1. Literature review & theoretical foundation.
2. Hyperspectral imager hardware development.
3. Optical and spectral simulation.
4. Validation and feasibility assessment.

Each phase contributes to addressing research gaps in cost-effective coral monitoring using hyperspectral imaging.

Literature Review & Theoretical Foundation

A comprehensive literature review was conducted above to understand already existing technologies and their applications towards coral health assessment. This included an analysis of:

- Traditional coral monitoring techniques like RGB imaging, satellite remote sensing, and underwater spectrometry and their limitations.
- Advancements in hyperspectral imaging and its relevance for early coral stress detection.
- Cost-effective imager development, including recent trends in miniaturization and affordability.

Hyperspectral Imager Hardware Development

The hardware development process focuses on designing a low-cost, compact hyperspectral imaging (HSI) system. This process, however, is subject to change if and when a step is unfeasible, or changes are made since this is purely theoretical. The key design choices include:

1. Optical design and sensor selection:

- Spectrographic-based approach 1:
  One possible route is using a holographic grating spectrograph such as the Specim ImSpector V10E since it has an already established performance and has potential for integrating with various cameras (Abd-Elrahman et al., 2011). The spectral range should be 400 - 1000 nm, and the spectral resolution should be 2.8 nm. When selecting a camera to pair with a spectrograph, key factors like spectral response range, spatial and radiometric resolution, and frame rate should be considered. The system, in the Abd-Elrahman et al. paper, uses the Imperx IPX-2M30H-L digital camera with a Charge-Coupled Device (CCD) sensor.
- Spectrographic-based approach 2:
  Another spectrographic setup uses a Raspberry Pi NoIR Camera Module V2.1, which features an 8 MP Sony IMX219 CMOS sensor with a pixel size of 1.12 μm × 1.12 μm and no infrared filter making it suitable for capturing both visible and near-infrared wavelengths (Pechlivani et al., 2023). The camera captures high-quality images and is connected to a Raspberry Pi 4 single-board computer with 8 GB of RAM, which manages image processing and storage. This design achieves a spectral range of 379-937 nm which captures about 290 wavebands, which offers a spectral resolution of 1.92 nm per band.
- Metasurface-based approach:
  A more compact and emerging alternative involves using AI-designed nanophotonic metasurfaces that filter light directly at the sensor level (Makarenko et al., 2022). These systems often use open-source tools like ALFRED for spectral pattern optimization and a Raspberry Pi for control and processing. A conventional monochrome camera can be used as the imaging sensor, with emphasis on matching the pixel size to the metasurface sub-pixel array and ensuring sufficient frame rate.

2. Lens and light source considerations:

- Lens for spectrograph-based systems:
  Lens choice should be based on field of view, light sensitivity (f-number), and compatibility with the spectrograph's opening. The Abd-Elrahman et al. study used a Schneider-Kreuznach Xenoplan lens, though off-the-shelf C-mount lenses may offer a more affordable option.
- Lens for metasurface-based systems:
  Any standard imaging lens compatible with the selected monochrome camera can be used to focus light onto the metasurface (Makarenko et al., 2022).

The selection criteria are based on conventional photography, like the field of view and light sensitivity.

- Lighting setup:
  - Passive hyperspectral imaging depends on ambient natural light, making it simpler but less controllable (Pechlivani et al., 2023).
  - Active hyperspectral imaging uses controlled light sources, such as broadband LEDs or supercontinuum lasers, which improves spectral consistency but can significantly increase cost and power requirements.

Optical and Spectral Simulation

Since in-situ measurements are not going to be done at this stage, the imager's performance is evaluated through simulations of alternative photoactive terrestrial organisms that mimic coral properties. As was mentioned earlier, these setups include: the exploration of photoactive terrestrial organisms that undergo color or pigmentation changes in response to environmental stress like plants, leaves, algae, and fungi; calcium carbonate samples that replicate coral skeletal structures like seashells or coral skeletons (if allowed); and artificially pigmented surfaces to reflect specific wavelengths similar to coral tissues mimic coral properties like using fluorescent dyes or ultraviolet paints (Bergamonti et al., 2011).

However, in aquatic environments, light undergoes absorption where the water molecules absorb light with longer wavelengths (red) more rapidly than with shorter wavelengths (blue-green) (Liu et al., 2020). The absorption affects the intensity and spectral composition of light as it penetrates deeper into the water column. Light attenuation can distort the spectral reflectance measurements of corals or other benthic features at different depths. Some water molecules and particles suspended in the water like sediments or pollutants that cause turbidity, might also scatter light, redirecting the light and causing diffusion. This scattering can blur images and alter the apparent color of submerged objects like corals or other benthic objects.

Therefore, to account for color distortion caused by absorption and scattering, adjustments in spectral calibration will be considered. To replicate the underwater light environment during these terrestrial experiments, optical filters or computational correction models can be used (Wetzstein et al., 2011):

1. Optical filtering:

- Bandpass filters:
  These filters transmit specific wavelength ranges while blocking others, allowing simulation for selective absorption characteristics of water. For instance, using filters that attenuate red wavelengths can replicate the rapid absorption of red light in water.
- Dichroic filters:
  These filters reflect certain wavelengths while transmitting others, enabling the creation of lighting conditions that resemble the underwater spectral environment.

2. Computational correction methods:

- Semi-analytical models:
  These models can predict how light interacts with water by incorporating factors like absorption coefficients and scattering properties (Niu et al., 2024).
- Radiative transfer models:
  These models simulate the transmission of light through water, allowing for the adjustment of spectral data to account for depth-related changes in light quality (Li et al., 2017).

These can help refine the accuracy of spectral data collected on land for future underwater applications.

Validation and Feasibility Assessment

The final step involves assessing the technical feasibility and cost-effectiveness of the hyperspectral imager:

- Accuracy evaluation:
  The spectral response of the imager is compared to standard hyperspectral imaging benchmarks.
- Cost analysis:
  A cost breakdown is conducted to assess the affordability of the prototype compared to commercial hyperspectral sensors.
- Future improvements:
  - Recommendations for miniaturization and improved spectral resolution are outlined.
  - The potential for integration with drones or underwater vehicles is discussed.

Conclusion

The literature review highlights the pressing need for enhanced coral reef monitoring due to significant threats like coral bleaching, which are escalating despite decades of awareness. Traditional coral health assessment methods, relying on diver-based surveys and RGB imaging, are limited by subjectivity, high labor demands, and their inability to detect coral stress in its early stages due to a lack of sufficient spectral sensitivity. While RGB imaging only captures broad bands of visible light, making early detection of pigment loss challenging, hyperspectral imaging (HSI) emerges as a powerful alternative by acquiring detailed spectral information across numerous narrow bands. This capability holds the potential for earlier and more precise detection of coral stress by analyzing specific spectral signatures related to coral pigments. However, the widespread adoption of HSI for coral monitoring has been hindered by the high cost and bulkiness of conventional HSI systems. Recent technological advancements, including the development of metasurfaces and integration with conventional monochrome cameras, offer promising methods for creating more affordable and compact HSI solutions. Despite these advancements, a significant research gap remains in validating the effectiveness and feasibility of low-cost HSI systems specifically for the unique challenges of coral health monitoring.

The proposed research methodology, employing a proof-of-concept framework, directly addresses the limitations of current monitoring techniques and the existing research gap. By focusing on the hardware development of a low-cost hyperspectral imager, and exploring both spectrographic and potentially metasurface-based designs, this study aims to tackle the affordability barrier. Recognizing the logistical challenges of immediate underwater testing, the methodology includes optical and spectral simulation using photoactive terrestrial organisms to mimic coral properties, allowing for an initial evaluation of the imager's spectral capabilities. The planned validation and feasibility assessment, encompassing accuracy evaluation and cost analysis, are crucial steps in determining the potential of such a system for practical coral monitoring. This approach, while acknowledging limitations like the absence of initial underwater validation, provides a necessary foundation for future refinements. For the practical implementation of a low-cost hyperspectral imager for coral health monitoring, several future directions are essential. Firstly, improving the spectral resolution and accuracy of the low-cost imager while maintaining its affordability should be a primary focus. Subsequently, comprehensive in-situ underwater validation in diverse reef environments will be critical to assess its performance under real-world conditions. Exploring the integration of the HSI system with autonomous platforms such as UAVs and ROVs/UUVs could enable large-scale and remote monitoring capabilities, reducing the reliance on divers and expanding spatial coverage. The development of user-friendly software and data processing pipelines, potentially incorporating machine learning algorithms for automated coral health assessment, will be crucial for making the technology accessible to a broader range of users. Investigating the use of custom-designed, low-cost optics could further optimize the imager's performance for underwater spectral imaging. Finally, collaboration with local marine researchers and conservation stakeholders will be vital to ensure the practical utility and adoption of the developed technology in addressing real-world coral reef conservation needs.

References

- Abd-Elrahman, A., Pande-Chhetri, R., & Vallad, G. (2011). Design and Development of a Multi-Purpose Low-Cost Hyperspectral Imaging System. https://www.mdpi.com/2072-4292/3/3/570.
- Baker, A., Glynn, P. W., & Riegl, B. (2008). Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. https://www.sciencedirect.com/science/article/abs/pii/S0272771408003405.
- Baston, G., & Qian, J. (2015). Review of Advancements in Hyperspectral Imaging for Low-Light Environments. https://osf.io/jv3p7_v1/download/?format=pdf.
- Bergamonti, L., Bersani, D., Csermely, D., & Lottici, P. P. (2011). The Nature of the Pigments in Corals and Pearls: A Contribution from Raman Spectroscopy. https://www.tandfonline.com/doi/abs/10.1080/00387010.2011.610399.
- Brown, B. E., Dunne, R. P., & Chansang, H. (1996). Coral bleaching relative to elevated seawater temperature in the Andaman Sea (Indian Ocean) over the last 50 years. https://www.researchgate.net/publication/226070355_Coral_bleaching_relative_to_elevated_seawater_temperature_in_the_Andaman_Sea_Indian_Ocean_over_the_last_50_years.
- Carlson, R. R., Evans, L. J., Foo, S. A., Grady, B. W., Li, J., Seeley, M., Xu, Y., & Asner, G. P. (2021). Synergistic benefits of conserving land-sea ecosystems. S2351989421002341.
- Casella, E., Collin, A., Harris, D., Ferse, S., Bejarano, S., Parravicini, V., Hench, J. L., & Rovere, A. (2016). Mapping coral reefs using consumer-grade drones and structure from motion photogrammetry techniques. https://people.duke.edu/~jlh82/pubs/Casella_et_al_2017_CR.pdf.
- Clark, R. N. (1999). Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy. https://www.ugpti.org/smartse/research/citations/downloads/Clark-Manual_Spectroscopy_Rocks_Minerals_Book-1999.pdf.
- English, S., Wilkinson, C., & Baker, V. (1997). Survey manual for tropical marine resources. https://www.aims.gov.au/sites/default/files/Survey%20Manual-sm01.pdf.
- Fitt, W. K., McFarland, F. K., Warner, M. E., & Chilcoat, G. C. (2000). Seasonal patterns of tissue biomass and densities of symbiotic dinoflagellates in reef corals and relation to coral bleaching. https://www.aoml.noaa.gov/general/lib/CREWS/Cleo/Exuma/RG_exu27.pdf.
- Foo, S. A., & Asner, G. P. (2019). Scaling Up Coral Reef Restoration Using Remote Sensing Technology. https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2019.00079/full.
- global.canon. (2025). CMOS Sensors. https://global.canon/en/technology/s_labo/light/003/05.html#:~:text=Like%20CCDs%2C%20CMOS.
- Goetz, A. F. H., Vane, G., Solomon, J. E., & Rock, B. N. (1985). Imaging Spectrometry for Earth Remote Sensing. https://www.science.org/doi/10.1126/science.228.4704.1147.
- Govender, M., Chetty, K., & Bulcock, H. (2007). A review of hyperspectral remote sensing and its application in vegetation and water resource studies. https://www.researchgate.net/publication/228781235_A_review_of_hyperspectral_remote_sensing_and_its_application_in_vegetation_and_water_resource_studies.
- Guannel, G., Arkema, K., Ruggiero, P., Verutes, G. (2016). The Power of Three: Coral Reefs, Seagrasses and Mangroves Protect Coastal Regions and Increase Their Resilience. https://repository.library.noaa.gov/view/noaa/24828.
- Hakala,T., Suomalainen, J., Kaasalainen, S., & Chen, Y. (2012). Full waveform hyperspectral LiDAR for terrestrial laser scanning. https://www.researchgate.net/publication/221978377_Full_waveform_hyperspectral_LiDAR_for_terrestrial_laser_scanning.

- Hedley, J. D., Roelfsema, C. M., Chollett, I., Harborne, A. R., Heron, S. F., Weeks, S., Skirving, W. J., Strong, A. E., Eakin, C. M., Christensen, T. R. L., Ticzon, V., Bejarano, S., & Mumby, P. J. (2016). Remote Sensing of Coral Reefs for Monitoring and Management: A Review. Remote Sensing of Coral Reefs for Monitoring and Management: A Review (mdpi.com).
- Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. https://www.publish.csiro.au/mf/pdf/MF99078.
- Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., Edwards, A. J., Caldeira, K., Knowlton, N., Eakin, C. M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R. H., Dubi, A., & Hatziolos, M. E. (2007). Coral Reefs Under Rapid Climate Change and Ocean Acidification. https://www.science.org/doi/10.1126/science.1152509.
- Holden, H., & LeDrew, E. (1998). Spectral Discrimination of Healthy and Non-Healthy Corals Based on Cluster Analysis, Principal Components Analysis, and Derivative Spectroscopy. https://www.sciencedirect.com/science/article/abs/pii/S0034425798000297.
- Huisman, T. (2023). Assessing the impact of temperature on coral bleaching in reef systems. https://fse.studenttheses.ub.rug.nl/30880/1/bBIO_2023_HuismanT.pdf.
- Li, J., Li, Z., Wang, P., Schmit, T. J., Bai, W., Atlas, R. (2017). An efficient radiative transfer model for hyperspectral IR radiance simulation and applications under cloudy-sky conditions. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016JD026273.
- Liu, B., Liu, Z., Men, S., Li, Y., Ding, Z., He, J., & Zhao, Z. (2020). Underwater Hyperspectral Imaging Technology and Its Applications for Detecting and Mapping the Seafloor: A Review. https://www.mdpi.com/1424-8220/20/17/4962.
- Makarenko, M., Burquete-Lopez, A., Wang, Q., Getman, F., Giancola, S., Ghanem, B., & Fratalocchi, A. (2022). Real-time Hyperspectral Imaging in Hardware via Trained Metasurface Encoders. https://arxiv.org/pdf/2204.02084.
- Niu, C., Tan, K., Wang, X., Du, P., & Pan, C. (2024). A semi-analytical approach for estimating inland water inherent optical properties and chlorophyll a using airborne hyperspectral imagery. https://www.sciencedirect.com/science/article/pii/S1569843224001286.
- Page, C. A., Field, S. N., Pollock, F. J., Lamb, J. B., Shedrawi, G., Wilson, S. K. (2016). Assessing coral health and disease from digital photographs and in situ surveys. https://static1.squarespace.com/static/53c8c0c7e4b0b8f450cea5bb/t/585f88d0bebafb65339e9238/1482655958514/Page+et+al+2017+Env+Mon+Ass%5B2%5D.pdf.
- Pechlivani, E. M., Papadimitriou, A., Pemas, S., Giakoumoglou, N., & Tzovaras, D. (2023). Low-Cost Hyperspectral Imaging Device for Portable Remote Sensing. https://www.mdpi.com/2410-390X/7/4/32. rgb.com. (2025). Visual Color Processing. https://www.rgb.com/visual-color-processing#:~:text=There%20are%20three%20types%20of,(peaking%20around%20575%20nm).
- Roche, R. C., Harvey, C.V., Harvey, J. J., Kavanagh, A. P., McDonald, M., Stein-Rostaing, V. R., & Turner, J. R. (2016). Recreational Diving Impacts on Coral Reefs and the Adoption Of Environmentally Responsible Practices within the SCUBA Diving Industry. Recreational Diving Impacts on Coral Reefs and the Adoption of Environmentally Responsible Practices within the SCUBA Diving Industry - PMC (nih.gov).
- Shah, N. (2024). Harnessing Hyperspectral Imaging: A Bird's-Eye View of Biodiversity Monitoring and Climate Conservation. https://www.pixxel.space/blogs/harnessing-hyperspectral-imaging-a-birds-eye-view-of-biodiversity-monitoring-and-climate-conservation.
- Stuart, M. B., McGonigle, A. JS., & Willmott, J. R.

(2019). Hyperspectral Imaging in Environmental Monitoring: A Review of Recent Developments and Technological Advances in Compact Field Deployable Systems. https://www.researchgate.net/publication/334405579_Hyperspectral_Imaging_in_Environmental_Monitoring_A_Review_of_Recent_Developments_and_Technological_Advances_in_Compact_Field_Deployable_Systems.

- Teague, J., Megson-Smith, D. A., Allen, M. J., Day, J. C. C., & Scott, T. B. (2020). A Review of Current Coral Monitoring Tools/ Diagnostic Methods & Introducing a New Tool to the Coral Health Toolkit. https://www.mdpi.com/2673-1924/3/1/3.
- Teague, J., & Scott, T. (2017). Underwater Photogrammetry and 3D Reconstruction of Submerged Objects in Shallow Environments by ROV and Underwater GPS. https://research-information.bris.ac.uk/ws/portalfiles/portal/136210068/Underwater_Photogrammetry_and_3D_Reconstruction.pdf.
- Velloth, S., Mupparthy, R., & Nayak, S. (2015). Hyperspectral Remote Sensing of Coral Reefs. https://www.researchgate.net/publication/274563533_Hyperspectral_Remote_Sensing_of_Coral_Reefs.
- Wetzstein, G., Ihrke, I., Lanman, D., & Heidrich, W. (2011). Computational Plenoptic Imaging. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8659.2011.02073.x.
- Zhou, J., Zhang, D., & Zhang, W. (2021). A multifeature fusion method for the color distortion and low contrast of underwater images. https://www.researchgate.net/publication/349140479_A_multifeature_fusion_method_for_the_color_distortion_and_low_contrast_of_underwater_images

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