The environmental impact and research characteristics of food systems in small island contexts. Case studies on food imports and a scoping review in Aruba, Bonaire, and Curacao (Dutch Caribbean)

FACULTY OF BIOSCIENCE ENGINEERING
DEPARTMENT OF BIOSYSTEMS
Willem de Croylaan 42 – box 2428
3001 LEUVEN, Belgium
www.kuleuven.be

Amber S. van Veghel
The environmental impact and research characteristics of food systems in small island contexts
April 2026

KU LEUVEN

Arenberg Doctoral School
Faculty of Bioscience Engineering

The environmental impact and research characteristics of food systems in small island contexts

Case studies on food imports and a scoping review in Aruba, Bonaire, and Curacao (Dutch Caribbean)

Amber S. van Veghel

Supervisors:
Promotor: Prof. Annemie Geeraerd Ameryckx
Co-promotor: Dr. Renske R. Pin
Co-promotor: Prof. Salys Sultan

Dissertation presented in partial fulfillment of the requirements for the degree of Doctor of Bioscience Engineering (PhD)

April 2026

THE ENVIRONMENTAL IMPACT AND RESEARCH CHARACTERISTICS OF FOOD SYSTEMS IN SMALL ISLAND CONTEXTS:

CASE STUDIES ON FOOD IMPORTS AND A SCOPING REVIEW IN ARUBA, BONAIRE, AND CURACAO (DUTCH CARIBBEAN)

Amber S. VAN VEGHEL

Supervisor(s):
Prof. A. Geeraerd Ameryckx
Dr. R.R. Pin
Prof. S. Sultan

Members of the Examination Committee:
Prof. D. Sakellariou, chair
Prof. R. DiPietro
Prof. M. Maertens
Prof. A. Van Rompaey
Prof. A. Di Maria

Dissertation presented in partial fulfilment of the requirements for the degree of Doctor of Bioscience Engineering (PhD)

April 2026

Doctoraatsproefschrift nr. 2065 aan de faculteit Bio-ingenieurswetenschappen van de KU Leuven

ISBN: 978-94-6537-405-5
Printed by Ridderprint, Alblasserdam, the Netherlands
Printed on FSC® certified recycled paper

Uitgegeven in eigen beheer, Amber S. van Veghel, Willemstad, Curaçao

To Jack

PREFACE

This story is based on non-chronological real-life island experiences

A DAY IN MY LIFE
My colleagues and I are dressed semi-formally. *Check*
Excited chatter fills the room. *Check*
The chairs in the front row of the aula are reserved. *Check*
This can only mean one thing.

The Governor of Aruba has made time in his busy schedule to visit the University of Aruba. Again. “Please rise for the arrival of the Governor of Aruba”. A sharp sound silences the chatter as the door of the aula opens. And there he is. A tall man with a friendly smile appears in the doorway, followed by his Adjudant who can be recognized by his white suit and white shoes. The Governor politely greets the attendees as he walks in. I remind myself that the role of this man is similar to that of the King of the Netherlands.

“All formalities established”. Yes, we also have a few ministers attending this conference. While everyone delivers their well-prepared speeches and presentations, the flag of Aruba proudly waves in the airconditioned room. Each colour containing a depth of symbolism and weaving together past, present, and future. I glance around the room and notice history books shaped like stained glass windows *(Dutch: glas in lood)* decorating this historic building.

“Next up is Amber van Veghel, PhD Candidate from the University of Aruba and KU Leuven”. Time to pitch why it is important to understand the environmental impact of our food. This is my chance to share with the audience that our global food system is under pressure, and that we are dependent on that system which also emits almost a third of global anthropogenic greenhouse gas emissions. As I make eye contact with the Prime Minister of Aruba, with who I would be on the same 19-person plane to Curaçao a few months later, I feel that my words are reaching the audience. I have their attention.

A few months later I run into a lady who attended my presentation. With a big smile, she proudly tells that during her last supermarket trip she bought only one pack of beef instead of three. She heard my voice whisper in her ear "Beef is one of the products with the highest carbon footprint". I am happy to see people making small changes. They matter.

RE-FOCUS

Time to shift gears and focus on my PhD research. The carbon footprint of vegetable imports to Aruba will not calculate itself. As I arrive at the University, I glance up at the beautiful heart-shaped Eucalyptus tree decorating the entrance. While greeting my colleagues I run into the rector, who greets me by name and asks how the conference went. We exchange some thoughts before I enter Tostaoo, the University cafeteria. "Hello Amber!" John greets me with a big smile. He knows exactly how I like my coffee, and I'm ready for another day of diving into Aruba's food chains. Before I start working, I order my favourite veggie quesadilla for lunch (they put grilled vegetables in!). John asks me at what time I would like it to be ready. "Can I eat at the same time as my colleagues?". John nods and tells me that Nigel, Kryss, and Micky ordered for 12.00 PM. And so do I.

BEING AN ISLAND RESEARCHER

During several research stays in Leuven (Belgium), I realized that my island reality, and I'm not talking about the sunsets and days at the ocean, is only a reality for a minority of people. This made me appreciate the "village feeling" even more, while valuing the opportunity I was granted to be part of the KU Leuven ecosystem with all its benefits. Being an island researcher comes with its own set of unique challenges and opportunities, but I wouldn't trade those for anything else. This is what I think defines us, island researchers, most:

We are both generalists and specialists;
We are flexible, adaptive, and quick learners;
We are relationship and community oriented.

But how can we not be, given the proximity to our government and our community, who are also the taxpayers enabling University employees to execute research.

THE SISSTEM PROGRAM

This PhD thesis is an output of the SISSTEM program of the University of Aruba which was initiated in 2019 in collaboration with KU Leuven, funded by the European Union (FED/2019/406-549) and supported by the Government of Aruba. SISSTEM stands for Sustainable Island Solutions through Science, Technology, Engineering, and Mathematics.

A MULTI-DISCIPLINARY PHD THESIS

The goal of the PhD was to explore how to apply the method Life Cycle Assessment (LCA) - used to quantify the environmental impact (e.g., CO_2 emissions, land use) of products or services – to quantify the sustainability of Aruba's food supply chains. Given the near import dependence of Aruba, I focused on food imports and designed detailed models to quantify sea and air transport routes in tourism-dependent small island contexts.

Throughout the course of this PhD, an increased interest from policymakers and citizens in food security and in increasing local food production was observed. Therefore, the focus expanded to exploring other approaches to research food in Aruba and the neighbouring islands Bonaire and Curaçao. Through a scoping review, we created a first-time overview of published research on food production, supply, and consumption. The results showed a great variety in the types of research executed and sparked my curiosity to continue exploring different sub-fields within the larger area of food and sustainability.

At SISSTEM we teach our students to become independent and critical thinkers who are adaptable and can quickly understand new concepts and methods to study our islands. I went on a similar journey and learned to systematically design and execute a scoping review according to internationally acknowledged protocols. This resulted in a multi-disciplinary PhD thesis that focuses on quantifying the environmental impact of food imports *and* provides an overview of research on food production, supply, and consumption in the ABC islands.

ACKNOWLEDGEMENTS

Thank you, my dear grandparents, for always supporting me and believing in me. Your hard work made it possible for the generations after you to study and work in the fields they choose.

Dutch: Dank jullie wel, lieve oma en opa, voor jullie voortdurende steun en vertrouwen. Jullie harde werk heeft het mogelijk gemaakt dat de generaties na jullie kunnen studeren en werken in de vakgebieden waar hun interesse ligt.

Thank you, my dear parents Manfred van Veghel and Ilinka van Veghel-Hellmund, for your conscious upbringing. I remember how we were raised with separating paper from other garbage and bringing plastic bottles back to the supermarket to be rewarded with the deposit. How else could two nature lovers raise their children? Perhaps these little moments sparked an intrinsic motivation to care for our planet. For me, this is expressed through food production and consumption, as my career has shown so far.

There are a few other people whom I want to thank. Without the opportunities I received before I started my PhD, I may never have started this PhD journey which partly focuses on quantifying the environmental impact of foods using Life Cycle Assessment (LCA).

In 2017, after a research group meeting of the Laboratory of Food Process Engineering from Wageningen University & Research, I had a short conversation with Professor Atze-Jan van der Goot at the escalator in the Forum building. He asked me what I wanted to do for my internship and I responded that I wanted to focus on sustainability. Thank you, Atze-Jan, for taking the time to introduce me to Blonk Consultants, where I later did my internship. And, for always being generous with your time and attention to the students, we all felt that. I still have warm memories from my time as a BSc and MSc student at the Laboratory, which is currently led by Professor Karin Schroën. Thank you, Karin, for writing and delivering the speech at my graduation ceremony. I still remember it.

Thank you, Hans Blonk, for giving me the opportunity to do my internship on the environmental impact of plant proteins at Blonk Consultants (now Mérieux NutriSciences | Blonk). Thank you, Roline Broekema, for guiding me. I still regularly receive messages from people interested in my internship report. The lunch conversations in Gouda helped me to better understand environmental impact measurements and shaped my thinking as a life cycle practitioner.

Thank you, Drees Peter van den Bosch, for hiring me in 2018 as an Impact Analyst at Willem&Drees (now: EkoMenu). We were pioneering in the then emerging field of carbon footprinting of foods and claiming CO_2 neutrality of foods in the Netherlands. Your vision and action on making fair food from a healthy food chain easily accessible to people inspire me and shaped my vision on sustainable food.

BACK TO THE CARIBBEAN

As a *yu di Kòrsou* (a child of Curaçao), I moved back to Curaçao in 2020. A big thank you again to my parents, who hosted me and with who I had a relaxed COVID-19 quarantine time. This is where I met Renske Pin, who sparked my interest in academia again. If it wasn't for us meeting and for you asking me to work with your team on a research proposal, I may not have returned to academia. With your experience and complementary background in communication and behavioural sciences it was a natural choice to ask you to be my co-promotor at the start of my PhD. I'm happy you agreed to fulfil this role.

Thank you, everyone who was part of initiating and executing the SISSTEM Program at the University of Aruba. SISSTEM stands for Sustainable Island Solutions through Science, Technology, Engineering, and Mathematics. Without this program, I could not have done my PhD. The story behind it is worth mentioning:

A group of dedicated individuals had a vision for creating an academic program in STEM in Aruba, to provide students the opportunity to study in their own regional context, to prevent brain drain and stimulate brain gain, and to increase local research capacity. You spent countless hours, days, and effort in writing a proposal to realize this grand vision. Then one day, Aruba's Prime Minister was sitting on the plane next to the vice-rector of KU Leuven and the rest was history. They agreed to support this agenda together. This was the start of a strong collaboration between the KU Leuven and the University of Aruba that continues until today.

Thank you for your perseverance, dedication, and vision. Doing a PhD in my own region and academic field is not something to take for granted in the Caribbean. Thank you, Patrick Arens, Eric Mijts, Bianca Peeters, and Glenn Thodé.

PHD

Thank you, Professor Annemie Geeraerd Ameryckx, for being my promotor and for guiding me in writing this PhD thesis and presenting the work at international conferences. Writing scientific articles, working on reviewer's comments and writing rebuttals is an art and with your guidance this became easier. Your careful remarks and eye for detail have improved the quality of my work. Your kindness, understanding, and patience made it a pleasant experience at the Sustainability of the Agri-Food Chain Group. I visited Leuven four times and enjoyed our group activities and lunches at the picnic bench. Thank you, colleagues from our Group: Freya Michiels, Klara Van Mierlo, Niels Demaitre, Aurore Guillaume, Villi Ieremia, Sarah Matthys and Margarita Baquero Rivadeneira! Thank you, students, whom I had the opportunity to supervise, especially Alice, who I collaborated with on a peer-reviewed paper. Thank you, Alexx, Hans and Matthias for your joyful presence at the office. Thank you, Maya and Phoebe, for the delicious coffees, walks around Leuven, and for being my friends. I hope the blue bike will stay in shape for a long time!

A special thank you to my co-promotors Prof. Salys Sultan and Dr. Renske Pin. Thank you for your critical and supportive questions. Salys, you always took the effort to express your appreciation for my work and approach to life. Your love for teaching and interest in the wellbeing of the people around you are remarkable. Renske, you helped me to view my PhD with a helicopter view and to continuously reflect on its societal contributions. During the final part of writing this manuscript we worked at the same office, coWorld in Otrobanda (Curaçao). I appreciated our conversations about what it means to be a researcher in our region. And at the point of writing, a researcher *and* an entrepreneur.

Thank you, University of Aruba, for hosting me for four years. Where should I start? The preface shows the warm and familiar feeling that I experienced at this special place. A place where we exchanged thoughts, enjoyed food together, and where I made new friends. Together, we set up a bachelor and master program in STEM, and we hosted and visited several international conferences related to small islands. Thank you, fellow PhD candidates, for walking this PhD journey together: Diego Acevedo (now a senior lecturer), Alba de Agustin, Tobia de Scisciolo, Kryss Facun, Sharona Jurgens, Francielle Lacle, Francis Lacle, Kailas Malwade, Diana Melville-Honeth, Jeltzlin Semerel, and Colleen Weekes. Thank you, senior staff who guided us: Eric Mijts, Nigel John, Michael Honeth, Salys Sultan, and Violeta López. Especially at the start of the program, Eric and Nigel moved mountains. Eric, you have been a constant pillar for the SISSTEM project, your ambition and drive to connect people, support people, envision brighter futures, and build and maintain networks are remarkable. Thank you, Patrick Arens, you supported the SISSTEM program, were always interested in our PhD journeys, and made us laugh with your jokes and stories. Thank you, Tatiana Becker, for always showing your interest in my work and for reading my articles. Thank you, dear students, it was an honour to teach and guide you and to witness your growth. I hope we may work together in the future!

But without the support of Pauline Veenendaal, Anouk Mertens, and Sander Görtz, I would not be writing this thesis. Pauline, you always ensured a smooth administration and communication within the team, and we share a love for animals. Anouk, you were the mother figure during our visits in Leuven, I enjoyed our early swims during your visits in Aruba, and you saved me when I got Covid during one of my research stays in Leuven. Your love for doing research on islands is inspiring. Sander, without your hard work I would not be able to defend my thesis at the new aula in the Maria Convent building. Cheers to that! There are countless other individuals at the University of Aruba with whom I had wonderful conversations and shared beautiful moments, you know who you are ;).

Thank you, Sustainable Diets Journal Club (SDJC), our bi-monthly online meetings with early career researchers across the globe have inspired me and showed me sub-fields within our field that I didn't know yet. Thank you, Alexandra Stern and Naglaa El-Abbadi, for founding the SDJC in 2018. Thank you, Aline Carvalho for organizing the meetings together with me, since 2022. Thank you, Isabela Camusso and Marhya Júlia Silva Leite, for your enthusiasm in assisting us. Thank you, Berill Takacs, I was inspired by your article on the environmental impact of

meat-based vs plant-based meals and invited you to speak at the SDJC. You turned into an appreciated sparring partner for my thesis!

Thank you, coWorld, my favourite co-working place in the Triangle building in Curaçao. When I moved back to Curaçao this became my steady office. Thank you, Karien, the mother of coWorld, your smile is as bright as the sun and your dedication to this place is felt. Thank you, Koen, for providing us with healthy, local, five-star meals! You gave me my first Curaçao sun-grown tomatoes, and I will never stop talking about how good they taste! Thank you, staff, colleagues, for the warmth, coffee breaks and inspiring conversations.

Thank you, members of the Examination Committee, for carefully reading my manuscript and for providing feedback. Your comments have improved my work. Thank you, big brother, for ensuring that the printed PhD manuscripts arrived in Belgium and across the Netherlands in time. Thank you, Diego Acevedo and Brechtje Huiskes, for accepting the role of paranymph during my public defence. Thank you again, Eric Mijts, for accepting the role of protocollary chair during my public defence in the aula of the University of Aruba.

Last but not least. Thank you, Aruba. I lived in Aruba for four years and this island has a special place in my heart. Luckily, I still visit Aruba frequently for business trips. I made dear friends in Aruba, you know who you are ;). I had the pleasure to start my journey in Aruba in a beautiful home near the entrance of Arikok National Park. Later, I moved to a wooden cabin at the foot of Sero Cristal (*Crystal Mountain)*, where bats roam freely at night and shocos (Aruba's super cute endemic burrowing owl) adorn the rocky landscape. Two beautiful experiences which ranged from magical bike rides, early walks and many snakes, to peaceful moments in nature. During the last one and a half years this was with Senna, a dog, by my side. Senna, you walked into my life and were such a gift and such a joy. Gilbert, I cannot thank you enough for taking over the care for Senna, who was by law forbidden to emigrate to Curaçao, and for giving her a home within a pack.

Thank you, Arawak people of Aruba, your spirit remains and your energy is still present and can be felt. Finally, I especially thank Eagle Beach, the North Coast, and Grapefield Beach for the beautiful time spent there. I wrote a poem to express my love and gratitude for living and working in Aruba for four years.

A POEM TO ARUBA

"Daydreaming"

I made a documentary, I play it on repeat
About my life in paradise, I think about it all the time

I can't stop daydreaming about you

Yellow birds sing their song, at this concert I belong
A big-eyed owl says hello, yes this is the place to go
Cunucu dogs everywhere, a wild donkey, stop and stare
A sissing snake in my way, a magic sunset every day
The ocean has all shades of blue, I'll never get enough of you
I feel the wind on my skin, I hear the waves and jump right in

I can't stop daydreaming about you

Cadushi my scenery, aloe my first aid
A thousand stars in the night, each of them shining bright
In every corner a new surprise, my hungry eyes are satisfied
Papaya bright as the sun, guava taste on my tongue
Moringa magic food, dragonfruit you taste good
Tamarind what a sweet treat, mango season wait for me

I can't stop daydreaming about you

Friendly people say hello, con a bay, how are you?
The fire burns in my heart, I know we will never part

Aruba, I love you
I will see you
Very soon

POPULAR ABSTRACT

Many countries, including small Caribbean islands, have become increasingly dependent on a global food system that is under growing pressure from human activities such as plastic pollution, land conversion, and climate change. While agriculture itself is a major driver of harm to the Earth's ecosystems. This dissertation focused on quantifying the environmental impact of Aruba's food imports and on mapping the existing body of research related to food in the ABC islands (Aruba, Bonaire, and Curacao in the Dutch Caribbean). First, two case studies – on canned tuna and vegetable imports – quantified the environmental impact of Aruba's food imports using a method called life cycle assessment (LCA). Impacts from sea and air transport were calculated in detail due to Aruba's remoteness and distance from major maritime transport routes. In addition, nearly all air-freighted foods were imported using passenger aircrafts, which may have different greenhouse gas (GHG) emission intensities than global averages. Results showed a generally low contribution of sea transport (despite a detailed modelling approach) and a high contribution of air transport to total GHG emissions of food imports. However, GHG emissions from specific passenger aircrafts attending Aruba were lower than global estimates. For canned tuna imports, differences in the environmental impact of three brands were minimal, although differences in supply chains were modelled in detail. Tuna in large cans had a lower environmental impact per kilogram tuna compared to small cans. For vegetable imports, those transported by sea had much lower GHG emissions compared to airfreighted vegetables, especially when road transport was relatively short. Second, current research on food production, supply, and consumption in the ABC islands showed a growing research field, a diverse local and international research community, a strong Dutch Kingdom and European orientation in collaboration and funding, and a diverse coverage of topics and food system aspects studied. Challenges and solutions to increase local food production and improving food security are well recorded. LCA may assist in specific aspects of food security planning, as part of a greater puzzle. Future projects, laws, regulations, and research should contribute to increasing food security, as well as provide insight in promoting locally acceptable dietary changes aimed at climate change mitigation and health.

POPULAIRE SAMENVATTING

Veel landen, waaronder kleine Caribische eilanden, zijn steeds afhankelijker geworden van een mondiaal voedselsysteem dat onder toenemende druk staat door menselijke activiteiten zoals plasticvervuiling, ontbossing, en klimaatverandering. Tegelijkertijd zijn voedselproductie en -consumptie een belangrijke veroorzaker van milieuschade, Dit proefschrift richt zich op het kwantificeren van de milieu-impact van voedselimport in Aruba, en het in kaart brengen van bestaand onderzoek naar voedsel in de ABC-eilanden (Aruba, Bonaire, en Curaçao) in Caribisch Nederland. Eerst zijn twee casestudies uitgevoerd – over de import van bliktonijn en groenten – om de milieu-impact van Aruba's voedselimport te berekenen met de methode levenscyclusanalyse (LCA). De bijdrage van zee- en luchttransport aan de milieu-impact van voedselimport werden in detail berekend. Aruba ligt namelijk ver weg van grote scheepvaartroutes, en voor luchttransport worden vrijwel enkel passagiersvliegtuigen gebruikt, met een mogelijk andere CO_2 uitstoot dan het gemiddelde vliegtuig. De resultaten lieten zien dat zeevracht over het algemeen maar een kleine rol speelt in de totale uitstoot van broeikasgassen van voedselimport (ondanks de gedetailleerde modellering), terwijl luchttransport een relatief grote bijdrage had. De uitstoot van de passagiersvluchten naar Aruba bleek wel lager vergeleken met algemene berekeningen. Voor geïmporteerde bliktonijn bleek het verschil in de milieu-impact tussen drie merken minimaal te zijn, ondanks een gedetailleerde modellering van de aanvoerketens. Zoals verwacht had tonijn in grotere blikken een lagere milieu-impact per kilogram tonijn vergeleken met kleinere blikken. Voor de import van groentes bleek dat groentes geïmporteerd per schip een lagere milieu-impact hadden vergeleken met groentes geïmporteerd per vliegtuig, vooral als het aandeel wegtransport relatief laag was. Daarna werd voor het eerst een overzicht gemaakt van bestaand onderzoek naar de voedselvoorziening, -productie, en -consumptie op de ABC-eilanden. De resultaten lieten een groeiende belangstelling voor dit onderzoeksgebied zien, een diverse en internationaal georiënteerde onderzoeksgemeenschap, een sterke oriëntatie richting het Nederlandse Koninkrijk en de Europese Unie wat betreft samenwerkingen en fondsen, en diversiteit in onderzochtte onderwerpen en aspecten van het voedselsysteem. Uitdagingen en oplossingen voor een verhoogde productie van lokaal voedsel en voedselzekerheid bleken goed onderzocht te zijn. LCA kan een rol spelen in bepaalde aspecten van het verhogen van de voedselzekerheid, als deel van een grotere puzzel. Toekomstige projecten, wet- en regelgeving, en onderzoek dienen oplossingen te vinden voor uitdagingen in het verhogen van de voedselzekerheid en het verwerven van inzicht in het promoten van lokaal geaccepteerde veranderingen in eetgewoontes die bijdragen aan de mitigatie van klimaatverandering en gezondheid.

SCIENTIFIC ABSTRACT

Many countries, including small Caribbean islands, have become increasingly dependent on a global food system that is under growing pressure from human activities such as plastic pollution, the conversion of nature to agricultural land, and climate change. While agriculture itself is a major driver of harm to the Earth's ecosystems. The food system causes almost a third of global greenhouse gas (GHG) emissions and drives almost 90% of global deforestation, mainly due to livestock production.

The goal of this dissertation was to apply the method Life Cycle Assessment (LCA) - used to quantify the environmental impact (e.g., CO_2 emissions, land use) of products or services – to foods in an island context. Throughout the PhD project, an increased interest from policymakers and citizens in food security and in increasing local food production was observed, as well as numerous research outputs related to food. Therefore, the focus expanded to exploring other approaches to research food in Aruba and the neighbouring islands Bonaire and Curacao (the ABC islands in the Dutch Caribbean).

This dissertation explored the question: *What is the environmental impact of an island's food imports, and how can its food system be studied through diverse analytical approaches?* To answer this question, two case studies were performed on the environmental impact of Aruba's food imports, on a product level (Chapter 2 on canned tuna imports from three different brands), and on a product category level (Chapter 3 on vegetable imports from 25 product-country combinations). The case studies were chosen due to their diversity in supply chains, production methods, and their importance to the scientific field of food and LCA as well as the Aruban diet. Then, a first-time overview of published research on food production, supply, and consumption was created (scoping review in chapter 4).

In two case studies, impacts from sea and air transport were calculated in detail, for two reasons. First, although it is generally known that sea transport contributes relatively little to total GHG emissions of food imports, this has been understudied for islands, which are situated further away from main maritime transport routes. Therefore, food imports to islands may require longer transport distances, longer

sailing times, and smaller vessel sizes, especially for the final part of the sailing trip, while the vessels may not always sail at maximum cargo capacities. Also, the environmental impact per kilogram product is higher for smaller vessels compared to larger vessels. Second, airfreighted foods are often imported to islands (and other tourist destinations) using passenger aircrafts. GHG emissions of imports by passenger aircrafts vary dependent on aircraft characteristics and may be different compared to general estimates. Results showed a generally low contribution of sea transport (despite a detailed modelling approach) and a high contribution of air transport to total GHG emissions of food imports. However, GHG emissions from specific passenger aircrafts attending Aruba were lower compared to generic data, which are used by many LCA practitioners.

At the product level, results from the three canned tuna brands showed similar environmental impacts because the main contributing supply chain stages were the same for the three brands and a detailed modelling of processing and transport stages did not generate large differences in environmental impact. As expected, canned tuna in large cans had a lower environmental impact per kilogram tuna compared to small cans. At the product category level, vegetables that were transported by sea had much lower GHG emissions compared to airfreighted vegetables, especially when road transport was relatively short.

Finally, research related to food supply, production, and consumption in the ABC islands was mapped for the first time. Nine databases were searched: academic databases, local university repositories, local knowledge repositories, and global knowledge repositories. Based on predefined inclusion criteria, 117 publications from 2000 – March 2025 were included. Results showed a growing research field, a diverse, local and international research community, a strong Dutch Kingdom and EU orientation in collaboration and funding, and a diverse coverage of topics and aspects of the food system studied. Challenges and solutions to increase local food production and improving food security are well recorded. LCA may assist in specific aspects of food security planning, as part of a greater puzzle. Future projects, laws, regulations, and research should contribute to increasing food security, as well as provide insight in promoting locally acceptable dietary changes aimed at climate change mitigation and health.

WETENSCHAPPELIJKE SAMENVATTING

Veel landen, waaronder kleine Caribische eilanden, zijn steeds afhankelijker geworden van een mondiaal voedselsysteem dat onder toenemende druk staat door menselijke activiteiten zoals plasticvervuiling, de omzetting van natuur naar landbouwgrond, en klimaatverandering. Tegelijkertijd is de landbouw zelf een belangrijke veroorzaker van milieuschade. Zo veroorzaakt het voedselsysteem bijna een derde van de wereldwijde CO_2 uitstoot en bijna 90% van de mondiale ontbossing, vooral door de productie van vee.

Het doel van dit doctoraat was om de methode levenscyclusanalyse (LCA) – gebruikt om de milieu-impact (bv., CO_2 emissies, landgebruik) van producten en diensten te meten – toe te passen op voedsel in een eiland context. Gedurende het doctoraat viel het op dat er veel interesse was van beleidsmakers en burgers in voedselzekerheid en in het verhogen van de lokale voedselproductie, alsmede veel onderzoeksactiviteiten gerelateerd aan voedsel. Daarom verbreedde het doel van het doctoraat naar het in kaart brengen van diverse manieren om zowel in Aruba als buureilanden Bonaire en Curaçao (de ABC eilanden in het Caribisch gebied) onderzoek te doen naar voedsel.

Dit proefschrift richtte zich op de vraag: *Wat is de milieu-impact van de voedselimport van een eiland, en hoe kan het voedselsysteem van een eiland bestudeerd worden met behulp van verschillende analytische methoden?*

Om deze vraag te beantwoorden, werden eerst twee casestudies uitgevoerd. Deze richtten zich op het kwantificeren van de milieu-impact van de voedselimport van Aruba, op productniveau (Hoofdstuk 2 - import van drie merken bliktonijn), en op productcategorieniveau (Hoofdstuk 3 - import van groenten uit 25 product-landcombinaties). De casestudies zijn gekozen vanwege hun uiteenlopende waardeketens, productiemethoden, wetenschappelijke relevantie binnen het LCA-veld en hun belang in het Arubaanse voedingspatroon. Vervolgens werd een overzicht gemaakt van onderzoek naar de voedselvoorziening, -productie, en -consumptie op de ABC-eilanden (Hoofdstuk 4 – via systematisch literatuuronderzoek, ook wel *een scoping review*).

In de casestudies werden de milieu-impact van zee- en luchttransport in detail berekend, om twee redenen. Alhoewel bekend is dat zeevracht doorgaans maar beperkt bijdraagt aan de totale CO_2 uitstoot van voedselimport, is dit nauwelijks onderzocht voor eilanden, die vaak ver van grote scheepvaartroutes liggen. Daardoor kan voedselimport naar eilanden langere afstanden, langere vaartijden en kleinere schepen vereisen, zeker in het laatste deel van de reis, waarbij schepen wellicht niet altijd op volle capaciteit varen. Ook hebben kleinere schepen een hogere milieubelasting per kilogram product dan grotere schepen. Ten tweede worden op eilanden (en andere toeristische bestemmingen) vaak producten per passagiersvliegtuig geïmporteerd. De CO_2 uitstoot van deze vluchten hangt af van de specifieke kenmerken van het vliegtuig en kan afwijken van de algemene data die vaak in LCA-studies wordt gebruikt.

De resultaten lieten zien dat zeevracht slechts een kleine bijdrage leverde aan de totale CO_2 uitstoot van voedselimport (ondanks de gedetailleerde modellering), terwijl luchttransport een relatief grote bijdrage had. Wel bleek dat de CO_2 uitstoot van passagiersvluchten naar Aruba toe lager was vergeleken met algemene data. Op productniveau vertoonden de drie onderzochte merken bliktonijn vergelijkbare milieueffecten. Het onderdeel van de waardeketen met de grootste bijdrage aan de milieu-impact, de visserij, was namelijk gelijk in de drie scenarios en een gedetailleerde modellering van verwerking en transport hadden weinig invloed op de milieu-impact. Op categorieniveau hadden per schip vervoerde groenten veel lagere emissies dan per vliegtuig ingevlogen groenten, vooral wanneer het wegtransport voor de scheepvaart beperkt bleef.

Tot slot werd onderzoek naar de voedselvoorziening, -productie, en -consumptie op de ABC-eilanden voor het eerst systematisch in kaart gebracht. Hiervoor werden negen databanken doorzocht – waaronder academische databases, lokale universiteits- en kennisarchieven, en internationale kennisarchieven. Op basis van vooraf vastgestelde selectiecriteria werden 117 publicaties uit de periode 2000 – Maart 2025 opgenomen. De resultaten lieten een groeiend onderzoeksveld zien, met een diverse lokale en internationale onderzoeksgemeenschap, sterke samenwerkingsverbanden binnen het Koninkrijk en de EU, en een brede dekking van themas en aspecten van het voedselsysteem. Uitdagingen en kansen om lokale voedselproductie en voedselzekerheid te verhogen zijn goed onderzocht. LCA kan een rol spelen in bepaalde aspecten van het verhogen van de voedselzekerheid, als onderdeel van een grotere puzzel. Toekomstige projecten, wet- en regelgeving, en onderzoek dienen oplossingen te vinden voor uitdagingen in het verhogen van de voedselzekerheid en het verweven van inzicht in het promoten van lokaal geaccepteerde veranderingen in eetgewoontes die bijdragen aan de mitigatie van klimaatverandering en verhoging van de gezondheid.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AW	Aruba
AC	Acidification
ABAS agenda	Antigua and Barbuda Agenda for SIDS
ABC	Aruba, Bonaire, Curacao
BES	Bonaire, Sint Eustatius, Saba
BQ-BO	Bonaire
BQ-SA	Saba
BQ-SE	Sint Eustatius
CW	Curacao
CBS	Central Bureau of Statistics
CA	Canada
CC	Climate Change
CO	Colombia
COVID-19	Coronavirus disease
DCALFA	Dutch Caribbean Agriculture, Livestock, and Fisheries Alliance
DO	Dominican Republic
DUFB Program	Double Up Food Bucks Program
DWT	Deadweight Tonnage
EOW	Empty Operating Weight
ES	Spain
EUTF	Freshwater eutrophication
EUTM	Marine eutrophication
EUTT	Terrestrial eutrophication
FAO	Food and Agricultural Organization
FAOSTAT`	Food and Agricultural Organization Statistics
FRTOX	Freshwater ecotoxicity
FUE	Fuel Use Efficiency
GCD	Great circle distance
GHG	Greenhouse gas
GT	Guatemala
GWP	Global Warming Potential
HTCE	Human toxicity, cancer effects
HTNCE	Human toxicity, non-cancer effects

ICAO	International Civil Aviation Organization
ILCD	International Reference Life Cycle Data System
IRHH	Ionizing radiation HH (human health)
IRE	Ionizing radiation E (ecosystem)
ISO	International Standard Organization
IT	Italy
KE	Kenya
LAC region	Latin America and the Caribbean
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCA	Life Cycle Assessment
LU	Land use
MA	Morocco
MLW	Maximum Landing Weight
MFRRD	Mineral, fossil & renewable resource depletion
MTOW	Maximum Take-Off Weight
MX	Mexico
MZFW	Maximum Zero Fuel Weight
NEPP	Nature and Environment Policy Plan Caribbean Netherlands
NL	the Netherlands
NWO	Dutch Research Council
ODP	Ozone depletion
PAR	Participatory action research
PE	Peru
PICTs	Pacific Island Countries and Territories
PM	Particulate matter
POF	Photochemical ozone formation
RDC	Regional Distribution Centre
RO	Research Objective
SCAC	South and Central America and the Caribbean
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SISSTEM	Sustainable Island Solutions through Science, Technology, Engineering and Mathematics
SITE	Small Island Tourism Economy

SSS	Saba, Sint Eustatius, Sint Maarten
SXM	Sint Maarten
tkm	tonne kilometre
UA	University of Aruba
UK	United Kingdom
ULD	Unit Load Device
UoC	University of Curacao
US	United States
VE	Venezuela
WEB	Water- en energiebedrijf
WEF nexus	Water-energy-food nexus
WD	Water resource depletion
WWF	World Wildlife Fund

PART I

SETTING THE SCENE

CHAPTER 1 GENERAL INTRODUCTION

This dissertation focuses on calculating the environmental impact of an island's food imports, as well as mapping the characteristics of existing research related to food production, supply, and consumption in Aruba, Bonaire, and Curacao (the ABC islands situated in the Caribbean Sea, North of Venezuela). The ABC islands are part of the Dutch Kingdom which comprises of the Netherlands and six Dutch Caribbean islands (Government of the Netherlands, 2025). To introduce the main results of this doctoral dissertation, three topics will be introduced. First, challenges faced and caused by the global food system will be introduced. Second, the method life cycle assessment (LCA) will be explained, focusing on its application to quantify the environmental impact of foods and the relevance of transport for small islands. Third, the geographical context and of the ABC islands will be introduced. Finally, the aim and objectives of this doctoral dissertation are formulated.

1.1 CHALLENGES FACED AND CAUSED BY THE GLOBAL FOOD SYSTEM

An increasing food import dependence has been observed globally (Kummu et al., 2020; Porkka et al., 2013) and is a common characteristic of small islands as well (Brugulat-Panés et al., 2025; FAO, 2016). Global agricultural systems are particularly vulnerable to climate change impacts (Chimi et al., 2025; FAO, 2023). Climate change has caused increased crop prices and a weakening of food supply chains, caused by changes in temperature, rainfall, and increased pest and disease outbreaks (Nguyen et al., 2024; Rezaei et al., 2025; Tchonkouang et al., 2024). In the Caribbean, climate change will have a significant effect on agriculture and fisheries, mainly through water availability and changing weather, air and sea surface temperature patterns (Lincoln Lenderking et al., 2021).

The Intergovernmental Panel on Climate Change (IPCC) acknowledged the relationship between climate change, agriculture, and food security in their first assessment report in 1990 (IPCC, 1992). Food systems relate to all the SDGs and are interlinked with other sectors, such as the energy and health sector (HLPE, 2020). “A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes” (HLPE, 2014). Food systems also contribute to almost a third of total anthropogenic greenhouse gas (GHG) emissions (Babiker et al., 2022; Crippa et al., 2021; Rockström et al., 2025; S. J. Vermeulen et al., 2012), almost 90% of global deforestation (Branthomme et al., 2023). Most global freshwater use is for agriculture (Hoekstra & Mekonnen, 2012) and freshwater consumption of agriculture is increasing globally (Chukalla et al., 2025).

Over the past two decades, attention for sustainable food systems, agricultural sustainability, and sustainable food consumption has increased (Chimi et al., 2025; Diaconeasa et al., 2024; van Dooren et al., 2024). In 2021, the first United Nations Summit dedicated to Food Systems was organized. This summit aimed at using the power of food systems to progress on all 17 Sustainable Development Goals (SDGs). The SDGs are embraced by many islands, including all six Dutch Caribbean islands, which are all members of the Local2030 Islands Network which “is the world’s first global, island-led network devoted to addressing the climate crisis by advancing the SDGs through locally driven, culturally informed solutions” (Local2030 Islands Network, 2025).

The mitigation potential of food systems is recognized by the IPCC (Babiker et al., 2022) and stressed by Rockström et al. (2025), who stated that “no safe solution to climate and biodiversity crises is possible without a global food systems transformation. Even if a global energy transition away from fossil fuels occurs, food systems will cause the world to breach the Paris Climate agreement of limiting global mean surface temperature to 1.5°C”. Both small islands and international institutions are concerned about insufficient global mitigation efforts and demand accelerated action (IPCC, 2023; United Nations, 2024, 2024; United Nations Environment Programme, 2024).

1.2 LIFE CYCLE ASSESSMENT (LCA)

Life Cycle Assessment (LCA) is a widely used tool to “assess the potential environmental impacts and resources used throughout a product’s life cycle, i.e. from raw material acquisition, via production and use stages, to waste management” (ISO, 2006b). LCA emerged in the 1960s and has since been in constant development. In 1989 and 1990, the first widely used commercial LCA software programs GaBi (now Sphera) and SimaPro were released, respectively (Greenhouse Gas Protocol, n.d.; PRé, 2025). In 1996, the first academic journal fully dedicated to LCA, The International Journal of Life Cycle Assessment, was founded (Springer Nature, 2025). The number of scientific publications that use LCA in the field of agriculture or food has grown in the past two decades (Clune et al., 2017; Koblianska et al., 2024).

LCA can be used for various applications. For example, to compare the environmental impact of products within the same product category, to compare the environmental impact of sectors, or to assist in process design for increasing the sustainability of a product. LCA results may be unexpected and may go against the gut-feeling of people. To illustrate, it is often claimed that local foods have lower GHG emissions than imported foods, because less transportation is required. However, GHG emissions of a food product cannot be linked directly to their transportation distance, as other supply chain stages also emit GHG emissions (Stein & Santini, 2022). The production stage tends to be the biggest contributor to GHG emissions of food consumption (Notarnicola, Tassielli, et al., 2017).

1.2.1 Methodology

LCA is an ISO certified method that consists of five phases: goal definition, scope definition, inventory analysis, impact assessment, and interpretation (ISO, 2006a). The five phases are depicted in fig. 1-1, where the arrows between the boxes indicate the iterative approach of LCA. For example, a goal may be set at the start of conducting an LCA, but when a lack of data is discovered in a later phase, this goal may not be attainable and should thus be adjusted. Now, the five phases will be explained, based on (Hauschild, 2018a).

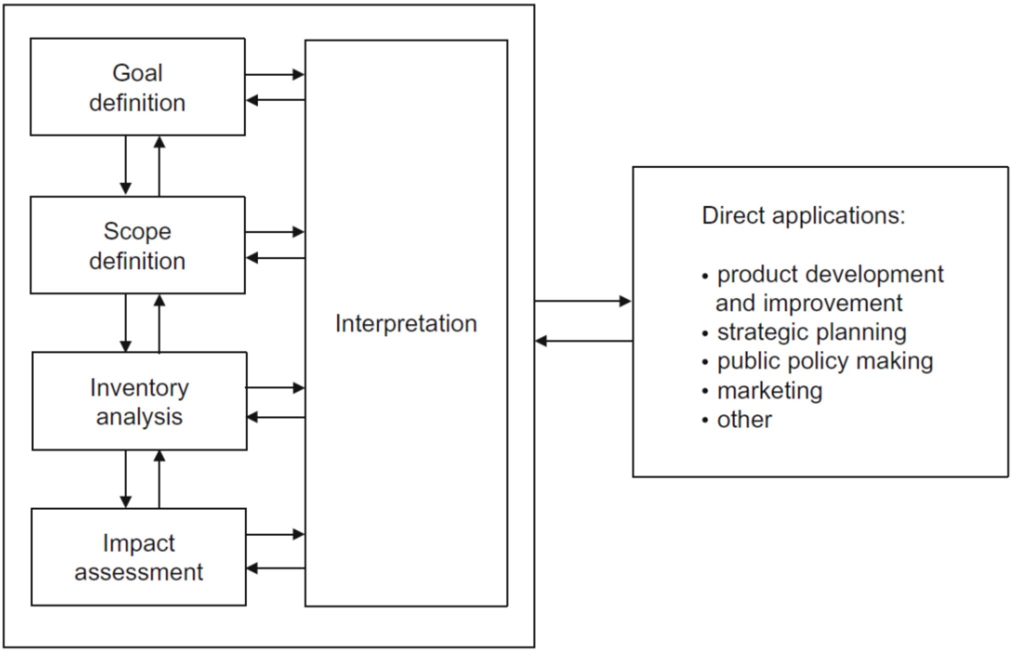

Figure 1-1 Phases and applications of life cycle assessment
Copied from Hauschild (2018).

The goal definition indicates why and for whom a study is performed, forming the basis of the scope definition. The scope definition includes the functional unit, which describes the product under study (e.g. 1 kg canned tuna at the supermarket in Aruba), how the environmental impact will be measured (e.g., in kg product, kg protein, or kg food consumption per person per day), and what the system boundaries are (e.g. farm-to-gate or farm-to-retail). Also, the environmental impacts of interest, geographical and temporal boundaries, the technology level, the need to perform a critical review (in case of making environmental claims), and the type of LCA should be mentioned.

The inventory analysis identifies the most suitable data sources in line with the goal and scope definitions. It consists of background and foreground data (e.g., on inputs, outputs, environmental impacts), scaled to the scope of the study. Background data can be sourced from a variety of sources, such as LCA databases, peer-reviewed articles, reports, web pages, or expert opinions. For example, the environmental impact of transport or electricity, which are commonly used processes, are usually retrieved from LCA databases, such as ecoinvent or Agri-Footprint.

The impact assessment consists of five elements (explained below), of which the first three are mandatory: 1. selection of impact categories, in line with the scope definition; 2. classification of elementary flows from the inventory; 3. characterization; 4. normalization; 5. grouping or weighting.

A selection of impact categories (step 1) should be made depending on the goal and scope of the study. Either a selection of impact categories is made, or all impact categories are assessed. When using LCA software, no additional effort is required to calculate the environmental impact of multiple impact categories, which does not imply that no additional effort is required for interpreting the results. Table 1-1 depicts an overview of midpoint+ impact categories as defined by the International Reference Life Cycle Data System (ILCD). Not all impact categories are equally robust yet, as LCA is a method in constant development (Benini et al., 2014; Verones et al., 2017). For example, results from the impact category climate change are more robust (level: very high) compared to ozone depletion (level: medium).

Elementary flows from the life cycle inventory are assigned to impact categories to which they contribute (step 2). This step is performed automatically in LCA software. For example, in the production of beef three different greenhouse gases are emitted: carbon dioxide, methane, and nitrous oxide. All three greenhouse gases contribute to the impact category climate change and are thus assigned to this impact category.

Subsequently, the elementary flows are characterized based on their contribution to an impact category (step 3). This step is performed automatically in LCA software. To illustrate, in the impact category climate change, a global warming potential is measured for each greenhouse gas, based on the amount of heat the gas traps compared to carbon dioxide. GHG emissions, or the carbon footprint, are therefore always measured in carbon dioxide equivalents (CO_2eq) and include the impact of non-CO_2 GHG emissions such as methane and nitrous oxide, which have characterization factors of 27 and 273, respectively (IPCC, 2021).

Table 1-1 ILCD 2011 Midpoint+ impact categories and robustness levels
Based on Benini et al. (2014).

Impact category	Abbreviation	Unit	Robustness level
Climate change	CC	kg CO_2 eq	Very high
Ozone depletion	ODP	kg CFC-11 eq	Medium
Human toxicity, cancer effect	HTCE	CTUh (Comparative Toxic Unit for humans)	Low
Human toxicity, non-cancer effect	HTNCE	CTUh (Comparative Toxic Unit for humans)	Low
Particulate matter	PM	kg PM2.5 eq	Very high
Ionizing radiation HH (human health)	IRHH	kBq U^{235} eq (to air)	Medium
Ionizing radiation E (ecosystem)	IRE	CTUe (Comparative Toxic Unit for ecosystems)	Not available
Photochemical ozone formation	POF	kg NMVOC eq	Medium
Acidification	AC	molc H+ eq	High
Terrestrial eutrophication	EUTT	molc N eq	Medium
Freshwater eutrophication	EUTF	kg P eq	Medium to Low
Marine eutrophication	EUTM	kg N eq	Medium to Low
Freshwater ecotoxicity	FRTOX	CTUe	Low
Land use	LU	kg C deficit	Medium
Water resource depletion	WD	m^3 water use related to local scarcity of water	Medium to Low
Mineral, fossil & renewable resource depletion	MFRRD	Kg Sb (antimony) eq	Medium

The optional normalization step (step 4) assists to identify the relative significance of each impact score, by comparing it to a reference system. In the optional weighting step (step 5), the impact scores of different impact categories are aggregated into one or a few single scores, to enable easier interpretation.

1.2.2 LCA to quantify the environmental impact of foods

LCA databases and methods

Data on the environmental impact of foods is available across different databases integrated into LCA software, as well as such as databases include excel databases or appendices of scientific papers. Examples of the former type are Agribalyse, Agri-Footprint, or the World Food LCA Database (WFLDB), among others. Examples of the latter type are such Poore & Nemecek (2018) or Clune et al. (2017). All databases have different advantages and disadvantages.

In chapter 2 on canned tuna imports, Agribalyse was selected as main database due to its availability of different types of fish. Although only canned tuna was studied, this study emerged from a master thesis which included salmon, shrimps, and pangasius as well (De Vlieghere, 2022). In chapter 3 on vegetable imports, the Poore & Nemecek (2018) database was selected due to a higher data availability of different vegetable types from various countries of origin.

A disadvantage of using different databases is the variation in methods which makes it more difficult to compare results (Clune et al., 2017; Goossens & Schmidt, 2025). To illustrate, the IPCC regularly updates characterization factors and for example adjusted the global warming potential (i.e., the amount of heat a greenhouse gas can trap) of the greenhouse gas methane from 28, to 34 and 27 kg CO_2 equivalents per kg methane, in 2006, 2013, and 2019, respectively (IPCC, 2006, 2013, 2021). The IPCC method used in chapter 2 was from 2006 while that from chapter 3 was from 2013.

GHG emissions of foods

LCA is commonly used to determine the environmental impact of foods. Although this section focuses on GHG emissions, it should be considered that trade-offs between different environmental impacts may exist and should be examined when making sustainable procurement decisions. For example, although nuts have relatively low GHG emissions, and the ability to capture carbon, they are among the foods with the highest water footprint and have a water footprint higher than some products with relatively high carbon footprints, such as beef (Poore & Nemecek, 2018).

Fig. 1-2 shows which foods generally have high or low GHG emissions, based on the Poore & Nemecek (2018) database. This database unified 570 agricultural studies and measures the environmental impact of foods from cradle-to-retail. Thus, including the following life cycle stages: farm (incl. deforestation), transport, packaging, processing, losses. Using a database with a unified methodology is important, as results from LCA studies can usually not be directly compared due to methodological differences (Clune et al., 2017; Goossens & Schmidt, 2025).

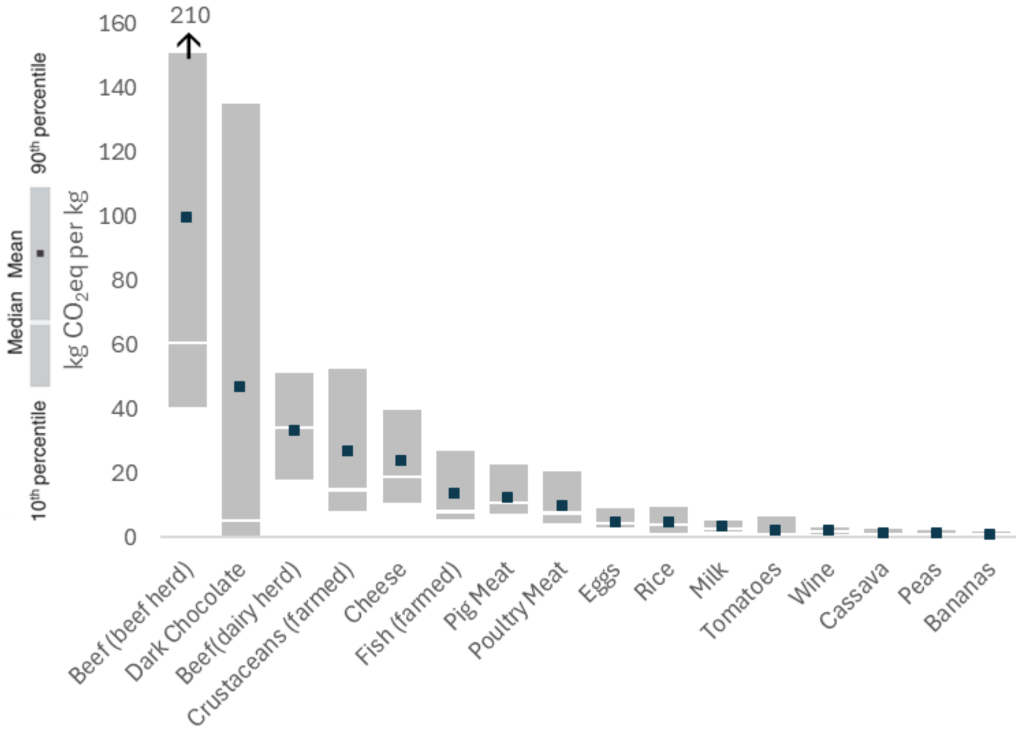

Figure 1-2 Estimated global variation in GHG emissions within and between 16 foods

Based on raw data on mean, 10th, 50th, and 90th percentile GHG emissions from Poore & Nemecek (2018).

Generally, animal-sourced foods have higher GHG emissions per kg product compared to plant-based foods (Clune et al., 2017; Poore & Nemecek, 2018). Beef and other ruminants (goat, sheep, lamb) are among the animal-sourced products that emit most GHG emissions per kg product, mostly due to enteric fermentation (releasing methane gases) and manure excretion (releasing nitrous oxide gases) (Gerber et al., 2013). Fig. 1-2 shows two types of beef, beef from beef herd and from dairy herd. GHG emissions of beef from dairy herd are generally lower because GHG emissions are allocated to both meat and milk production (Gerber et al., 2013). Fig. 1-2 also shows that the mean GHG emissions of dark chocolate are higher than those of beef from dairy herd, the median GHG emissions however are lower. This is because data on dark chocolate was for 28% based on dark chocolate from Indonesia (117 – 258 kg CO_2eq per kg) and most GHG emissions of this product-country combination were related to deforestation. Other data points on dark chocolate however reported GHG emissions not higher than 12 kg CO_2eq per kg.

The examples above illustrated a high variability in GHG emissions of animal-sourced products and other products related to deforestation, such as dark chocolate. Because, the relatively high GHG emissions from deforestation cause large differences between products where deforestation did or did not occur. To further illustrate, the highest GHG emissions recorded for beef from beef herd related to deforestation were 432 kg CO_2eq per kg. While the range of GHG emissions of beef not related to deforestation was 35 – 94 kg CO_2eq per kg. The variability is explained by differences in production methods, such as length of life and feed intake, as well as the intrinsic variability of food production systems (Notarnicola, Sala, et al., 2017; Poore & Nemecek, 2018).

Although animal-sourced products generally have higher GHG emissions, plant-based products may have higher GHG emissions in some cases, for three reasons. First, when products are related to deforestation, as discussed previously in the case of chocolate. Second, when large amounts of non-renewable energy were used in the production process. Such as for products grown in heated greenhouses (e.g., some tomatoes or lettuce). Casey et al. (2022) found that the carbon footprint of lettuce could vary 51-fold, where high emissions were recorded when fossil fuels were used for heating greenhouses during cultivation. For tomatoes, 78-fold differences were observed (Verteramo Chiu et al., 2024), for similar reasons. Third, when products were air freighted, as GHG emissions of air transport can typically contribute for 80% - 99% to total GHG emissions of a product (Frankowska et al., 2019; Michalský & Hooda, 2015; Sim et al., 2007).

The majority of LCA studies on food focused on Europe, North America, Oceania, Brazil, and China (Clune et al., 2017; Notarnicola, Sala, et al., 2017; Poore & Nemecek, 2018), and coverage of foods in Latin America and the Caribbean is limited (Marrero et al., 2022). Two examples of the limited LCAs on food imports in small island contexts focused on local chicken production and juice manufacturing. Thévenot et al. (2013) studied the environmental impact from cradle-to-slaughterhouse of different poultry production systems in Reúnion Island, situated East to Madagascar in the Indian Ocean. They found that acidifying and eutrophying emissions were caused dominantly on the farms itself and that GHG emissions were mostly caused by feed imports. Roibás et al. (2018) quantified GHG emissions from cradle-to-retail of ten fruit juices (per 250 mL bottle) produced in Malta, situated south of Italy in the Mediterranean Sea. They found that the juice which only contained local ingredients had a lower carbon footprint (0.50 kg CO_2eq per bottle) compared to other fruit juices (0.67 – 0.80 kg CO_2eq per bottle). The major contributor to GHG emissions was the processing step (0.42 kg CO_2eq per bottle), mainly due to the use of electricity based almost exclusively on oil combustion. Both studies provided little detail on the modelling of sea transport, which relevance for small islands is explained in the next section.

1.2.3 The role of transport and its relevance for small islands

Although air transport has relatively high GHG emissions, as explained above, transport in general usually contributes for only 5% to total GHG emissions of food consumption (Notarnicola, Tassielli, et al., 2017). However, GHG emissions of transport may be higher for vegetables and fruits, compared to other food products (Mengyu et al., 2022). This relatively high contribution of transport was due to temperature-controlled transportation. Although other food products were also transported in refrigerated containers, international transportation distances were generally longer for fruits and vegetables (Mengyu et al., 2022).

The contribution of transport to products will differ case per case. For example, Poore & Nemecek (2018, appendix: Database) found a contribution of transport to the GHG emissions of the categories 'Other vegetables', 'Onions & leeks', and 'Tomatoes' of 32%, 18% and 9%, respectively. For imports of relatively high-impact products, such as meat, sea transport has a negligible contribution to GHG emissions (Ziegler et al., 2021). Thus, transport can have a higher contribution to GHG emissions of relatively low-impact products, such as vegetables and fruits.

Given the contribution of transport to GHG emissions of relatively low-impact food imports and the remoteness of islands, it is interesting to explore the contribution of transport to total GHG emissions in an island context, for four reasons. First, small islands are often not situated on main maritime transport routes. This may require longer transport distances, longer sailing times, and smaller vessel sizes, especially for the final part of the sailing trip. Therefore, it is important to consider vessel size as the environmental impact per kg product is higher for smaller vessels compared to larger vessels (see table 1-2). Second, given the limited exports of small islands compared to larger countries, ships may sail back empty or continue their route without additional freight. As such, the environmental impacts for this “empty trip” are accounted to the imports of the small island. Third, ships sailing to islands may not always be fully loaded, resulting in higher GHG emissions per kg product. Fourth, airfreighted foods are often imported to islands, and other tourist destinations, using passenger aircrafts (Button, 2021). GHG emissions of imports using passenger aircrafts vary dependent on aircraft characteristics (Davydenko et al., 2020).

Table 1-2 shows differences in GHG emissions of different vessel sizes used for sea transport, as well as additional GHG emissions accounted for an empty trip back due to an island’s limited exports, and the effect of sailing without a full load. GHG emissions were retrieved from the LCA software SimaPro and were based on models of Klein et al. (2012a) and (2012b). Besides the trip length and cooling requirements, GHG emissions of sea transport depended on four factors.

First, the vessel size, measured in deadweight tonnage (DWT), indicates the total weight of cargo, fresh water, ballast water, fuel, passengers, provisions, and crew. Vessels with a higher DWT emit less GHG emissions per tonne km. As shown in the grey coloured boxes in table 1-2, sea transport using a 50,000 DWT ship emits 3.5x less GHG emissions compared to a similar transportation step with a 15,000 DWT ship. Second, the load factor indicates the cargo capacity used. A higher load factor leads to lower GHG emissions per kg product as the GHG emissions are divided over more products. Third, the trip length determines how long a ship is in the cruise phase (travelling at sea) which requires more engine power than slowly approaching a harbour. However, the difference in GHG emissions between trip lengths is relatively small (see the grey coloured boxes in table 1-2). Fourth, the model assumes higher GHG emissions when no new load is picked up at the port (empty return), which is likely for islands with very limited exports. GHG emissions of a short trip on a small vessel are 40% higher in the case of an empty return (Table 1-2).

Table 1-2 GHG emissions of sailing trips with different characteristics

GHG emissions were retrieved from SimaPro using Agri-footprint 4.0, using the IPCC 2013 GWP 100a (incl. carbon feedbacks) characterization method. DWT indicates the load a ship can carry. Trip lengths were short (< 5,000 km), middle (5,000 – 10,000 km), or long (> 10,000 km). Grey coloured boxes relate to the examples mentioned in the text. *The ship with a DWT of 50 was based on our own calculations (see chapter 3).

Vessel size (DWT)	Load factor (%)	Trip length	Empty return	GHG emissions (kg CO_2eq per tkm)
35,000	100%	Long	No	0.008
50,000	100%	Long	No	0.006
15,000	50%	Short	Yes	0.037
15,000	80%	Short	Yes	0.025
15,000	100%	Short	Yes	0.021
15,000	100%	Short	No	0.015
15,000	100%	Middle	No	0.014
15,000	100%	Long	No	0.014
10,000	80%	Short	Yes	0.037
50*	100%	Short	Yes	0.28

Calculating the environmental impact of food imports is a common application of LCA (e.g., Frankowska et al., 2019; Milà i Canals et al., 2008; Shrivastava et al., 2022) and is also relevant to small islands as they are increasingly dependent on the global food system due to their high food imports (FAO, 2016). Caribbean Small Island Developing States (SIDS) depend for over 80% of their food consumption on imports (FAO, 2016), driven by factors such as cost, status, taste, convenience and accessibility (Connell et al., 2020).

1.3 ISLAND CONTEXT

This doctoral study falls within the island studies category. This field started with a few strongly self-identified island studies researchers, mostly with an emphasis on governance, economy, and jurisdictional capacity. The field has emerged into a more diverse group of scholars from more varying geographical areas who are researching increasingly different topics, contributing to a more inclusive field (Grydehøj, 2023). Small islands specifically can be characterized by their small size, limited resources, geographic dispersion and isolation from markets (United Nations, 1992).

In 1994, the first sustainable development agenda for SIDS, the Barbados Programme of Action, was adopted on the first Global Conference on Sustainable Development of SIDS. Aiming to "set forth specific actions and measures to be taken at the national, regional and international levels in support of the sustainable development of SIDS", while recognizing the unique vulnerabilities and challenges SIDS are facing (United Nations, 1994). This development agenda was followed by the Mauritius Strategy in 2005 (United Nations, 2005) and the SAMOA Pathway in 2014 (United Nations, 2014). In 2024, the ABAS agenda marked a renewed declaration for resilient prosperity (United Nations, 2024).

1.3.1 Geographical context: the ABC islands in the Dutch Caribbean

The ABC islands are situated in the Caribbean Sea, north of Venezuela, and are part of the Kingdom of the Netherlands. The Kingdom consists of the Netherlands, three constituent countries (Aruba, Curacao, St. Maarten), and three special municipalities (Bonaire, Saba, St. Eustatius) (Government of the Netherlands, 2025). While the ABC islands lie in the south of the Caribbean, Saba, St. Eustatius, and St. Maarten are in the north (Fig. 1-3).

Table 1-3 depicts the size, population, and population density of the countries and special municipalities of the Kingdom of the Netherlands. The largest islands are Curacao, Bonaire, and Aruba. The population density of St. Maarten is highest (1,220 citizens per km^2) and much higher than those of the other islands.

Figure 1-3 Geographic location of countries and special municipalities in the Kingdom of the Netherlands

The Kingdom of the Netherlands consists of four countries (the Netherlands, Aruba, Curacao, St. Maarten) and three special municipalities (Bonaire, Saba, St. Eustatius). Adjusted from Kingdom of the Netherlands (2024).

Table 1-3 Size, population, and population density of the countries and special municipalities in the Kingdom of the Netherlands

(Government of the Netherlands, 2025; Statistics Netherlands, 2019, 2021).

Country / municipality	Size (km^2)	Population	Population density (Citizens / km^2)
Aruba	180	112,309 (2019)	631
Bonaire	288	20,104 (2019)	60
Curacao	444	158,665 (2019)	317
Saba	13	1,915 (2019)	152
St. Eustatius	21	3,138 (2019)	191
St. Maarten	34	41,486 (2016)	1,220
The Netherlands	42,000	17.28 million (2019)	411

Aruba and St. Maarten are globally among the islands that are most tourism dependent (Alberts, 2020; McElroy & Parry, 2010). Aruba's hospitality and tourism sector contributed more than 87% to the national GDP (International Monetary Fund, 2019). Bonaire and Curacao are also largely dependent on the tourism sector (D. Daal et al., 2021; Mak et al., 2025). The focus on tourism also indicates an increased need for food imports to supply food to tourists.

1.3.2 Local research agendas related to food

Food is also on the Caribbean research agenda of the NWO (Dutch Research Council), which is currently (October 2025) being finalized (NWO, 2025). This research agenda has been drafted through online surveys, expert sessions, community conversations, diaspora dialogues, stakeholder meetings, and written feedback, during 2019 – 2025. Currently, eight research themes have been identified, of which four relate, directly or indirectly, to food systems: (1) Economy, Creative Industry, Work & Migration; (2) Intergenerational Perspectives on Food, Nutrition, Joy in Movement & Holistic Health; (3) Healthy Ecosystem & Environment; (4) Health Care and Health Research.

1.3.3 Food production, supply, and consumption in the ABC islands

The ABC islands are nearly import dependent (Boyer et al., 2020; Hira et al., 2023; Moreno Ramirez, 2024; Somers, 2012; van den Heuvel, 2017). In Aruba, most imports originated from the United States (53 weight %), the Netherlands (19%), Brazil (5%), and Colombia (4%), based on the last port of consignment (CBS Aruba, personal communication, September 9, 2020). However, this does not indicate the first origin of the imported foods. For example, according to import statistics, most rice and chocolate imports were from the United States and the Netherlands (Trade Map, 2025), but both products are (obviously) not cultivated in the respective countries. In Curacao, most food imports originated from the Netherlands (36% of food import value), the United States (28%), Brazil (14%), and Colombia (7%) (Hira et al., 2023). Recent and complete data on food imports for Bonaire is not available due to simplifications made in the process of declaring goods (van Geelen, 2020). However, data from 2018 showed that Bonaire imported most fruits and vegetables from the United States (65% of food import value), the Netherlands (25%) and Curacao (4%) (CBS, 2020), where Curacao acted as a transit port (Brouwer et al., 2019; van Geelen, 2020). Curacao functions as a central hub for Bonaire (Brouwer et al., 2019) and data on food exports from Curacao to Bonaire is available (Central Bureau of Statistics Curaçao, personal communication, February 22, 2022).

These imported foods are expensive on all three islands, caused by high transportation costs and double taxing issues (Aruba Fair Trade Authority, 2024; van Geelen, 2020). To the author's knowledge, detailed data on food consumption of locals is only available for Aruba. Although food import data is available for Aruba and Curacao (Bleukx et al., 2021; Boyer et al., 2020; Couwet et al., 2022; Hira et al., 2023), it cannot give insight into which foods and in which quantities are consumed by citizens or tourists. Aruba did execute an income & expenditure survey in 2016 and has detailed insight in food procurement patterns by households (CBS Aruba, 2019). In 2025, the Department of Public Health in Aruba started the Total Diet Study which examines the food consumption of Aruban citizens using dietary recalls (Gobierno Aruba, 2025).

Local production in Aruba is shown in table 1-4. Almost one third of eggs and 12% of lettuce were produced locally. For goat meat, beef, pork, and fish, this was 5% or less. No data was available on the production of chicken, honey, fruits and vegetables other than lettuce, and processed products produced from either locally or imported foods. Some local processing facilities produced beer, spirits, yoghurt, and wine from locally grown grapes. However, the former three products were produced from imported raw materials.

Eating and drinking habits are generally unhealthy, which is also visible thorough the high prevalence of overweight and obesity across the ABC islands. The percentage of adults who are overweight or obese are 88%, 74%, and 65% in Aruba, Bonaire, and Curacao, respectively (CBS, 2025; Ministry of Tourism and Public Health et al., 2024; Verstraeten et al., 2017). In Bonaire, this increased from 61% to 74% from 2013 to 2021 (CBS, 2025). Results from national health surveys in Aruba and Curacao showed that over 84% of adults do not consume the

recommended intake of fruits and/or vegetables (Ministry of Tourism and Public Health et al., 2024; Verstraeten et al., 2017). In Bonaire, fruit and vegetable intake

Table 1-4 Local production in Aruba and its contribution to the total food supply

The percentage of the total food supply was calculated based on Aruba's food imports from 2023. *The average weight of an egg was assumed to be 60 grams (Travel et al., 2011). **Lettuce in Aruba weighs 200 – 250 g per head (Diego Acevedo, personal communication, May 23, 2025)

Product	Yearly local production	Contribution to total food supply (%)	Source
Goat or sheep meat	2023: 20.3 tonne	3%	(Veterinary Services Aruba, personal communication, February 23, 2025)
Beef	2023: 1.6 tonne	0.03%	
Pork	2023: 57.0 tonne	2%	
Fish	2003 – 2011: 145 – 169 tonne	5%	(Boekhoudt & Hadicurari, 2015)
Eggs*	2020: 801,900 dozen or 577 tonne	29%	(Sociaal Economische Raad, 2020)
Lettuce**	500,000 heads or 112,500 tonne	12%	(Moreno Ramirez, 2024)

recommended intake of fruits and/or vegetables (Ministry of Tourism and Public Health et al., 2024; Verstraeten et al., 2017). In Bonaire, fruit and vegetable intake was only measured in a survey with secondary school students. Only 16% of students stated they consumed the recommended fruit intake at least five days a week. However, 52% of students did consume meals that included vegetables at least five days per week (Bokern & Fernandez Beiro, 2025). In Curacao, almost one third of adults drink soft drinks daily, and 41% of adults eat at fast food restaurants weekly (Verstraeten et al., 2017). The author observed that many locals refer to *vegetables as food for rabbits*, and *water as drinks for fish*, illustrating the attitude towards healthy foods that some citizens may have.

1.4 AIM AND OBJECTIVES

This doctoral study aims to answer the following research question:

What is the environmental impact of an island's food imports, and how can its food system be studied through diverse analytical approaches?

To answer this question, three research objectives (RO) are identified. First, the environmental impact of food imports to Aruba (as a case study) are quantified from two viewpoints **(part II)**: through detailed modelling of the environmental impact of island-specific sea and air transport routes **(RO 1)** and through modelling the environmental impact at a food product- and food category level **(RO 2)**. Second, existing research on food production, supply, and consumption in the ABC islands is mapped through a scoping review **(part III – RO3)**. Then, insights are combined to inform LCA practitioners on our findings and to provide suggestions for future research on food in the ABC islands **(part IV)**. The three RO's are:

RO1 – To quantify the environmental impact of food transport to Aruba
An often-used method to quantify the environmental impact of products is Life Cycle Assessment (LCA). Typically, LCA studies on food imports focus on larger countries or continents and not on small islands. Such studies generally found a relatively low contribution of sea transport to greenhouse gas (GHG) emissions of sea freighted imports and a relatively high contribution of air transport for GHG emissions of air freighted imports. However, it has not often been studied if these findings remain valid in a small island context. Some characteristics of small islands may influence the environmental impact of their food imports: remote geographical location, limited exports, and the high tourism prevalence.

Due to their remoteness, small islands are often not situated on main maritime transport routes and larger vessels, with a lower environmental impact per kg product compared to smaller vessels, may not sail to small islands. Also, given the limited exports of small islands compared to larger countries, ships may sail back empty or continue sailing without additional freight. The environmental impact of this "empty trip" is then allocated to the food imports of the small island. Therefore, the environmental impact of actual maritime transport routes for food imports to Aruba will be quantified.

Due to the high prevalence of tourism, passenger aircrafts are commonly used to import foods to small islands (Button, 2021). The highest contributing factor to GHG emissions of air freighted foods is the air transport itself. However, many studies use a generic approach to calculate GHG emissions of air transport, while GHG emissions vary according to aircraft characteristics (Davydenko et al., 2020). Therefore, GHG emissions of air freighted food imports to Aruba will be quantified, using the characteristics of passenger aircrafts attending Aruba.

RO2 – To quantify the environmental impact of food import choices for Aruba
The environmental impact of imported foods is inherently variable due to differences in farming practices and supply chains. Given the near import dependence of Aruba, the environmental impacts of an imported food product and of a food category are modelled. Two case studies were chosen due to their diversity in supply chains, production methods, importance to the field of food and LCA, and their importance in the diet of Aruban citizens. The methods and modelling decisions will be described in detail for both case studies, for the purpose of transparency and reproducibility.

Canned tuna imports were studied because seafood is an understudied segment in the field of LCA (Ruiz-Salmón et al., 2021) and canned fish is among the basic consumer goods for which the price is regulated by the government of Aruba (DEACI, 2025). Among the canned fish imports, people spent most (69%) of their budget on canned tuna (CBS Aruba, 2019). Canned tuna can be imported from different brands, with different supply chains in terms of processing and the country of origin. Vegetable imports were studied because these were the most contributing food group when considering all air freighted food imports (37 weight%) (own calculations from data CBS Aruba, personal communication, March 11, 2021). Additionally, vegetables are imported from many different countries of origin, allowing to assess a variety of supply chains, and they play an important role in a healthy and sustainable diet (Rockström et al., 2025).

RO3 – To examine the characteristics of research on food production, supply, and consumption in Aruba, Bonaire, and Curacao
Considerable research related to food has been conducted in the ABC islands, yet much of it remains fragmented and poorly visible. Despite recognition of this gap

among researchers and stakeholders, no comprehensive overview has been available. Consolidating and mapping the existing body of work is therefore essential to support researchers, policymakers, and other stakeholders in developing a clearer understanding of this research domain and needs for future research. Therefore, a scoping review will be performed to create an overview of research and author characteristics, such as the research volume, topics and food types studied, and active authors and institutions. The focus of the scoping review will be on food production, supply, and consumption.

PART II

LCA TO QUANTIFY THE ENVIRONMENTAL IMPACT OF ARUBA'S FOOD IMPORTS

CHAPTER 2 LIFE CYCLE ASSESSMENT OF IMPORTING CANNED TUNA INTO ARUBA

THROUGH DIFERENT SUPPLY CHAINS, IN VARYING CAN SIZES AND IN OILS, BRINE OR TOMATO SAUCE

This chapter is based on: 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. *International Journal of Life Cycle Assessment*, *28*(11), 1577–1589. https://doi.org/10.1007/s11367-023-02207-4

*Alice De Vlieghere and Amber S. van Veghel shared first authorship. This article was based on the master thesis of A. De Vlieghere which was supervised by A.S. van Veghel.

CRediT authorship contribution statement
A.S. van Veghel: Conceptualization, Methodology, Investigation, Supervision, Writing – Review & Editing

2.1 ABSTRACT

Purpose: About 82% of the seafood consumed in Aruba is imported. Among canned fish products, tuna is consumed mostly. The purpose of this research was to compare the environmental impact of different types of canned tuna, and to identify environmental hotspots within the supply chains. Three comparisons were made: between three brands of canned tuna, between six accompanying liquids (oils, brine, and tomato sauce), and between small and large cans.

Methods: Life cycle assessment (LCA) was used to calculate the environmental impact of "1 kg edible tuna at the distribution centre in Aruba, including packaging", from the fishing stage until the distribution centre in Aruba. An Agribalyse tuna model was selected as the basis of the models and was adjusted in SimaPro. Adjusted processes were tuna species consumption mix, electricity mix during canning, size of cans, packaging, sea and truck transport, accompanying liquids, and storage. Added processes were transport in country of origin, and use of frozen loins (for one supply chain).

Results and discussion: Generally speaking, the observed differences in environmental impact in the three different comparisons were quite small. After normalization, seven environmental impact indicators were selected as most relevant. Environmental hotspots were usually related to diesel combustion on the fishing vessel, or to steel production in the canning stage. Although packaging was modelled with attention to detail, and sea transport was modelled with attention to detail for the used vessels and vessel characteristics, these were not one of the environmental hotspots.

Conclusions and recommendations: Although differences in environmental impact were quite small, most outstanding were that canned tuna that had the longest and partly frozen sea transport supply chain had the highest environmental impact. Preference should be given to local canning activities instead of shipping frozen tuna over long distances before canning. Further, large cans always had a lower environmental impact compared to small cans. From a hospitality or consumer point of view, it can be recommended to select larger can sizes where practically possible. The choice of tuna canned in tomato sauce, oil,

or brine would necessitate an analysis including the subsequent steps, for example, tuna canned in tomato sauce may be part of a meal as such, while tuna canned in brine may be prepared, after opening the can, with another warm or cold sauce, which would lead to additional separate impacts for these sauces.

Keywords: Seafood, Aruba, Life cycle assessment (LCA), tuna, supply chain

2.2 INTRODUCTION

Global seafood production is increasing year after year. Aquaculture production in particular is on the rise. Within the period 1990-2018, the global aquaculture production increased by 527% (FAO, 2020). The global seafood production is expected to continue to grow due to the increasing world population and increasing demand for animal protein especially in emerging countries where income is growing (FAO, 2020; Farmery et al., 2014). In wild-capture fisheries, the production and combustion of fossil fuel used on the vessels appear to be the main sources of greenhouse gas (GHG) emissions (Vázquez-Rowe et al., 2012). 75-95% of the total carbon footprint of wild-captured species can be traced back to the fishing stage with fuel use as main driver. The second most important driver of GHG emissions during the fishing stage is the use of refrigerants on the fishing boats (Ziegler et al., 2016). Capture fisheries also affect the stock size of target and non-target species, cause physical changes in the seabed, release chemicals and waste in the ocean, and cause eutrophication (Farmery et al., 2014; O'Neill & Ivanovic, 2016; Pelletier & Tyedmers, 2007; Vázquez-Rowe et al., 2012).

One of the biggest gaps in seafood LCA is the gap in geographic coverage. As also highlighted in the research of Vázquez-Rowe et al. (2012) and by Prof. Peter Tyedmers during his invited lecture on seafood sustainability at LCA Food 2022 (Lima, Perú), seafood LCAs are strongly biased towards industrialized countries. Moreover, the lack of transparency in seafood LCA literature results in a big data hurdle for those who want to perform a seafood LCA. Most of the authors do not reveal which life cycle inventory (LCI) data they used and which assumptions they made, making it difficult for others to further build on their findings. Also, the LCI databases which are available such as ecoinvent and Agri-footprint contain restricted data concerning seafood production (Bohnes & Laurent, 2021). These challenges impede the widespread adoption of seafood LCA, making it difficult to assess the environmental impact of these products (Bohnes et al., 2019).

In Aruba, an island in the Dutch Caribbean situated north to Venezuela, the average seafood consumption per capita was 53 kilograms per year (in 2015 – 2017). In the same period, the global average seafood consumption per capita was 20 kilograms, showing that the seafood consumption in Aruba is high (National Marine Fisheries Service, 2021). The Aruban seafood production, however, is rather low compared with the demand. Approximately 82% of the seafood consumed in Aruba is imported (own calculations based on Pauly et al. (2015); personal communication CBS Aruba, dataset food imports 2019, September 9, 2020). Typical about Aruba's fish imports is that most registered fish imports are by sea (~ 94%) rather than by air (own calculations based on personal communication Central Bureau of Statistics (CBS) Aruba, dataset food imports 2019, September 9, 2020). Fish imported by sea arrives mostly frozen or in cans. Compared to other canned fish products, people spent most (69%) of their budget on canned tuna (CBS Aruba, 2019).

In 2018, skipjack tuna (Katsuwonus pelamis) was the third most captured species worldwide following anchoveta and Alaska pollock (FAO, 2020). 64% of the world's tuna products originate from the Pacific Ocean and the dominant fishing technique is purse seining. Skipjack, albacore (*Thunnus alalunga*), and yellowfin (*Thunnus albacares*) tuna are mainly used for the canning industry, while bluefin (*Thunnus thynnus*) and bigeye tuna (*Thunnus obesus*) are the main species used for sashimi and sushi. World's top exporter of canned and processed tuna is Thailand with Bangkok being the heart of the global tuna processing industry. The largest importers of processed and canned tuna are the United States and the European Union (FAO, 2021).

The objective of this research is to assess the environmental impact and environmental hotspots of different brands and types of canned tuna imports into Aruba, with a focus on three comparisons. First, the environmental impact of three different brands of canned tuna, originating from Thailand or Peru. Second, the environmental impact of six different accompanying liquids i.e. oils or sauces. Third, the environmental impact of a small (0.142 kg) and a large (1.88 kg) can size.

The larger cans are sold in supermarkets but also used in the hospitality industry. To our knowledge, comparisons between the environmental impact of tuna can sizes and between different accompanying liquids have not been made before. Moreover, we will provide extensive details on our methods, such as the use of LCIs and databases.

2.3 METHODS

The ISO 14040 and the ISO 14044 standards were used in this study (European Commission et al., 2010).

2.3.1 Data collection

First, the target products were identified. Then we collected detailed data on the supply chains of the different brands of canned tuna by interpreting information on the packaging, through various online sources, and by materials provided by stakeholders in Aruba.

2.3.2 Identification of target products

To make a realistic selection of the types of canned tuna sold in Aruba, seven differently sized supermarkets were visited in May 2021 and pictures were taken of the shelfs and individual products (Fig. 2-1). It was assumed that the number of facings represented the popularity of a specific type of canned tuna. The most abundant brands were Sa-Pac, Brunswick, Santa Rita, Chicken of the Sea, and Bumble Bee. Canned tuna brands with different supply chain characteristics were selected. Santa Rita and Sa-Pac tuna were caught and canned in Peru and Thailand, respectively. Tuna from the three other brands was caught and pre-processed into frozen loins in Thailand and shipped to the cannery in the United States. As most information was available on the Chicken of the Sea supply chain, the brands Brunswick and Bumble Bee were not selected for this study. Most of the tuna sold in Aruba is canned in vegetable, sunflower, or soybean oil. Other liquids such as brine, olive oil, and tomato sauce were sold as well in lower amounts.

Figure 2-1 Canned tuna products in a supermarket in Aruba
Sa-Pac and Santa Rita canned tuna (top) and Chicken of the Sea canned tuna (bottom).

2.3.3 Goal and scope definition

The goal of this study is to assess the environmental impact of canned tuna imports to Aruba, and to compare the environmental impact of different supply chains, accompanying liquids, and can sizes. By performing an attributional LCA, environmental hotspots in the seafood supply chains were identified.

The functional unit is 1 kg edible tuna at the distribution centre in Aruba, including packaging. This study performs a cradle-to-gate LCA where the gate refers to the distribution centre in Aruba. All transport steps between the supply chain stages, as well as the transport of the packaging material, were considered. Fig. 2-2 shows the system boundaries as well as how the Agribalyse tuna process was adjusted. The coloured boxes and texts indicate which processes were adjusted (beige), except necessary scaling, or added (turquoise). Where possible, supply chains were adjusted to represent the Aruban case study, as elaborated on in detail in the next section.

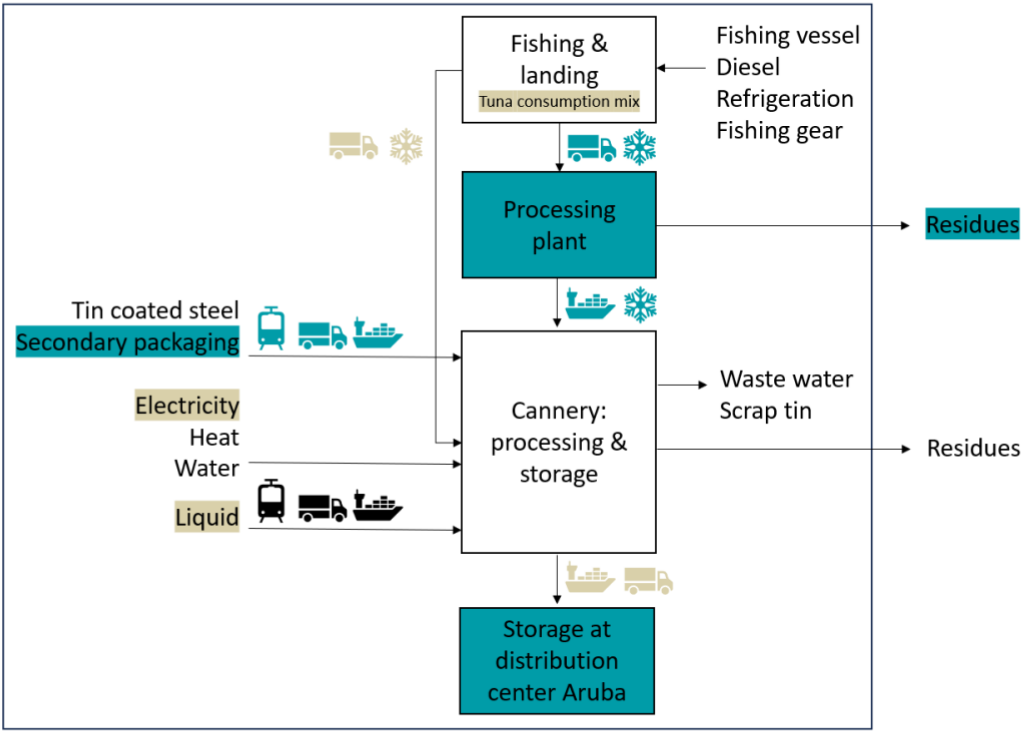

Figure 2-2 System boundaries of LCA on canned tuna imports into Aruba

Graphical representation of the canned tuna models based on the Agribalyse process "Tuna, flaked in oil, canned, drained, processed in FR | Ambient (average) | Already packed Aluminium | at distribution/FR". White boxes indicate processes that were re-scaled. Beige boxes indicate that processes were adjusted by adding primary data and/or improving geographic representation. Turquoise boxes indicate that new life cycle stages were added.

2.3.4 Process description and Life Cycle Inventory

The Agribalyse tuna process was used as the basis for this research: "Tuna, flaked, in oil, canned, drained, processed in FR | Ambient (average) | Already packed - Aluminium | at distribution/FR". It was modified to the Aruban case study by adapting the tuna model (species and accompanying liquids), geographical range, the packaging material, transport routes and modes, and storage. The background processes in Agribalyse originate from the database ecoinvent. To adjust the tuna model, background processes of the databases ecoinvent and Agri-footprint were used. Seafood datasets from Agribalyse used the system model 'Allocation, cut-off'. The reason Agribalyse used this system model as default for seafood datasets is a lack of data on the multifunctionality of seafood products (Asselin-Balençon et al., 2020). Therefore, this system model was also selected when datasets from the database ecoinvent were used.

Fishing stage

The tuna system started with the fishing activity, related to fishing and fish on vessels. This included the construction, maintenance, and end-of-life treatment of the vessels and the fishing gear. The model did not supply data on catches of non-target species, also referred to as by-catch. The Agribalyse model on the fishing stage was adjusted by altering the caught species. Chicken of the Sea tuna included the species skipjack, yellowfin, and albacore tuna (Chicken of the Sea, 2020). Sa-Pac and Santa Rita did not disclose information on the tuna species in their products. As not sufficient information was available for all brands, we assumed a similar tuna mix of 90% skipjack tuna and 10% yellowfin tuna.

LCI's of wild capture and aquaculture in the context of the Sustainable Recycling Industry program where the ecoinvent association is in charge of developing national LCA data in several regions and countries are available in the report of Avadí & Vázquez-Rowe (2019). Herein, a Fuel Use Efficiency (FUE, i.e., the volume of diesel that is needed to capture and land one ton of fish) of 831.6 L/t in Ecuador is indicated as being similar to FUE values reported for other purse seining tuna fisheries reported in Parker & Tyedmers (2015). Hence the fishing stage Agribalyse model was not adapted to the specific fishing areas in this study. Instead, the life cycle inventory (LCI) was based on a float of four worldwide average fishing vessels for tuna using purse seine fishing.

Truck transport

For all products, truck transport occurred between the fishing port and the processing facility, between the processing facility and the export port, and from the port of Barcadera in Aruba to the distribution center in Aruba. For Chicken of the Sea, truck transport also occurred between the port and the cannery in the United States. The transport between the fishing harbor and the processing facility occurred without packaging in a refrigerated truck (Noal Farm, 2018). This was modelled with the ecoinvent process "Transport, freight, lorry with reefer, freezing

{GLO}| market for | Cut-off, S". The transport step from the cannery to the export port was modelled with the ecoinvent process "Transport, freight, lorry 16-32 metric ton, EURO*X* {GLO}| market for | Cut-off, S". EURO norms used for modelling truck transport are depicted in table 2-1.

Table 2-1 EURO norms in countries where truck transport was modelled

Country	EURO norm	Source
Vietnam	EURO4	(EMLEG, 2018)
Thailand	EURO3	(TransportPolicy.net, 2018b)
Peru	EURO4	(TransportPolicy.net, 2018a)
Europe	EURO6	(Velders et al., 2013)
United States	EURO6	(TransportPolicy.net, 2018c)

Chicken of the Sea canned tuna was caught in the FAO Area 71 in the Western Central Pacific Ocean. The caught tuna was processed into frozen loins in Thailand in a Thai Union facility, this was assumed to be the Thai Union Manufacturing Plant 2, which was located 10 km from the fishing port and 45 km from the Port of Bangkok. After pre-processing, the frozen loins were shipped in a reefer (i.e., a refrigerated container) to the cannery in Lyons in the United States to be further processed into canned tuna. This port was chosen as it was located closest to the Port of Savannah (Chicken of the Sea, 2020). The distance from the port of Savannah to the cannery was 135 km.

Santa Rita canned tuna was caught in Peru and canned in the canning factory 'Inversiones y Comercio Internacional SRL' in Lima. The port of Callao was assumed to be both the fishing and export port, this port was located 20 km from the canning factory. The transport to the cannery was frozen transport, while the transport away from the cannery was ambient. The canned tuna was exported by ship via Cartagena in Colombia.

Sa-Pac canned tuna was caught and canned in Thailand. The canning and processing facility was Unicord Public Company Limited. A fishing port along the Tha Chin River located 10 km from the processing facility was chosen as representative fishing port. The processing facility was located 45 km from the Port of Bangkok. From there, the tuna was shipped directly from Thailand to Aruba, without passing by any distribution centre.

Packaging

The primary packaging was adjusted by using the weights of small tuna cans collected in Aruba, and the weight of a large tuna can from a restaurant in Aruba. The amount of oil and tinplate used in this process was adapted to the amount of oil and tinplate used in the tuna cans that are most commonly sold in supermarkets or used by restaurants in Aruba i.e., tuna cans with a net weight of 142 and 1880 grams, for small and large cans respectively. Their drained weights were 113 and 1498 grams, respectively. For small and large cans, 0.022 and 0.01 m^2 of tin plated steel were used per kg drained tuna, respectively. Agribalyse used the conversion ratio 1 kg drained tuna/1.33 kg canned tuna. This conversion ratio, however, was adapted to the conversion ratio of canned tuna products in this study; 1 kg drained tuna/1.61 kg canned tuna.

Secondary packaging was included by adding cardboard boxes, EUR-pallets, and the plastic around the boxes on the pallets. The weight and amount of cardboard boxes and pallets used was determined by interpolation of the data from the study of Hospido et al. (2006) (Table 2-2). In this study, the secondary packaging material is described for 660 kg drained tuna canned in small cans with an individual drained weight of 62 grams. Although the can size this research focuses on is larger, the assumption was made that the weight of the secondary packaging material was similar to the cans with a drained weight of 62 grams. EUR-pallets weighed 25 kg and are not re-used in Aruba but collected to use for other purposes (wholesaler Aruba, Feb 20, 2022). The plastic wrap weighed 0.64 kg and was obtained from an importer in Aruba.

Table 2-2 Weight of secondary packaging material

Based on Hospido et al. (2006).

Packaging material	660 kg drained tuna	1 kg drained tuna
Cardboard box (kg)	92.01	0.14
Plastic film (kg)	5.42	0.01
Pallet (unit)	2.08	0.003

Transport of the packaging materials was modelled using default distances specified by the Product Environmental Footprint Category Rules Guidance

(PEFCR) of the European Commissions (European Commission, 2017). It was assumed that the EURO norm of vehicles in each country complied with the obligated Euro norm for that country (Table 2-1). Although none of the focus species are packed in Europe, the PEFCR values were used since no such detailed default transport distances are available for other regions of the world. To model the transport distances the PEFCR differentiates two transport scenarios: the packaging supplier of the European packaging facility is located outside Europe or within Europe. It was assumed that the factory of the packaging material was not located on a different continent than the packaging facility. Therefore, the distances of the scenario of a packaging supplier within Europe were assumed. Distances and LCI's used, as specified by the PEFCR document, are depicted in table 2-3.

Table 2-3 Default transport distances and ecoinvent processes for packaging materials

Based on a supplier within Europe to a European packaging facility, according to the PEFCR.

Transport mode	Transport distance (km)	ecoinvent process
Lorry	230	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S
Freight train	280	Transport, freight train {RER}| market group for transport, freight train | Cut-off, S
Barge ship	360	Transport, freight, inland waterways, barge {RER}| processing | Cut-off, S

The PEFCR also specifies which ecoinvent transport processes should be used. The European geographic range {RER} was substituted for the correct geographic range of the lorry, train, and ship transport. Additionally, the Euro norm of the lorry transport specified by the PEFCR (EURO6), was substituted for the obligated Euro norm in the country/geographic range of the packaging facility (Table 2-1).

Accompanying liquids

The Agribalyse model assumed canning in vegetable oil, which was a mixture of 6.62% cottonseed oil, 47.05% palm oil and 46.33% soybean oil. To model the different accompanying liquids, the LCI's depicted in table 2-4 were selected. For small and large cans, 257 grams and 382 grams of accompanying liquid were used per kg drained tuna, respectively.

Table 2-4 SimaPro processes used for accompanying liquids

These processes substitute the ecoinvent process 'Vegetable oil, refined {GLO}| market for | Cut-off, U'.

Canning style	SimaPro process	Database
Tuna canned in brine	Tap water {GLO}| market group for | Cut-off, U	ecoinvent
Tuna canned in soybean oil	Soybean oil, at plant/FR U	Agribalyse
Tuna canned in sunflower oil	Sunflower oil, at plant/FR U	Agribalyse
Tuna canned in olive oil	Olive oil, at plant/FR U	Agribalyse
Tuna canned in tomato sauce	Basque-style sauce or tomato sauce with sweet peppers, prepacked, at plant/FR U	Agribalyse

Overseas transport

To model the shipping routes, durations, and distances we used the schedule on cma-cgm.com, one of the largest shipping companies (AXSMarine, 2022). The possible routes were the same for Chicken of the Sea and Santa Rita canned tuna, two different routes were possible for Sa-Pac canned tuna. For Sa-Pac tuna, an average route was based on two possible routes. Details on transshipments, ports, ship size, sailing distances, and transit days are provided in table 2-5. Via marinetraffic.com the ship size, expressed as deadweight tonnage (DWT) of the ships was determined.

The DWT of a ship indicates the load capacity. It is the total weight of cargo, fresh water, ballast water, fuel, passengers, provisions, and crew. The summer DWT differs from the winter DWT since the density of water declines in summer due to thermal expansion. Consequently, a sea ship floats deeper in the water during summer and can carry less cargo (Maritime Impact, 2020).

Table 2-5 Container ship characteristics, sailing times, and distances

Route	Trips between ports	Summer DWT	Distance (km)	Total distance (km)	Average total distance (km)	Average total transit days
Sa-Pac tuna						
1. Thailand – South Korea – Jamaica – Aruba	Bangkok → Busan	15,000	5,600	23,065	26,024	43.1
	Busan → Kingston	120,000	16,525			
	Kingston → Barcadera	10,000	940			
2. Thailand – Hong Kong – Panama – Aruba	Bangkok → Hong Kong	15,000	2,708	28,982		
	Hong Kong → Colón	120,000	24,630			
	Colón → Barcadera	10,000	1,644			
Santa-Rita tuna						
Peru – Colombia – Aruba	Callao → Cartagena	120,000	3,140	4,932	4,932	13.1
	Cartagena → Barcadera	15,000	1,792			
Chicken of the Sea tuna						
Thailand – Singapore – US – Jamaica – Aruba	Frozen: Bangkok → Singapore	15,000	1,526	29,858	29,858	Frozen: 43.5 Ambient: 12.2
	Frozen: Singapore → Savannah	120,000	24,764			
	Ambient: Savannah → Kingston	10,000	2,383			
	Ambient: Kingston → Barcadera	15,000	1,185			

LCI's from Agri-footprint were used as these allowed to select different characteristics, such as: DWT, load factor (LF), distance (short, middle, long), 'default' or 'empty return'. It was assumed that all ships had an LF of 100%. Except for the ship with the last transshipment to Aruba, which was assumed to have a LF of 80%, since Aruba is not situated at a main maritime transport route. All ships arriving in transhipment ports were assumed 'default'. The ships of the last transshipment were assumed to have an 'empty return', due to Aruba's limited exports. This is modelled as the return trip of the same distance with a 0% LF. 'Default' considers that sea ships may travel to a next port to pick up new load instead of returning to the original port of loading. To account for the refrigeration during transport, the LCI "Operation, reefer, freezing {GLO}| market for | Cut-off, S", expressed in kg*day, was selected.

Storage

Ambient storage was modelled according to the PEF guidance document (Asselin-Balençon et al., 2020), similar to Agribalyse's methodology. For Chicken of the Sea canned tuna it was assumed that no frozen storage occurred at the pre-processing plant in Thailand. It was assumed that products remained stored for one year.

2.3.5 Life Cycle Impact Assessment (LCIA)

The three mandatory steps of an LCIA – selection, classification, and characterization – were performed by the LCIA method ILCD 2011 Midpoint+ in SimaPro. Table 1-3 depicts an overview of all impact categories, their abbreviations, and unit. For the impact category climate change, characterisation factors from IPCC 2006 were included in the ILCD 2011 Midpoint+ method (IPCC, 2006).

External normalization of the environmental impacts was performed to interpret the results better. This optional step in LCIA compares the calculated impact scores to the scores of a reference system, identifying the relative significance of a certain impact score (Laurent & Hauschild, 2015). ILCD uses the normalization factors recommended by the Joint Research Centre which reflect the total impact of an average European person for the different impact categories for the reference year 2010 (Benini et al., 2014; Rosenbaum et al., 2018). Although the lifestyle of Europeans is different from the lifestyle of Arubans, the adoption of the average European impacts is justified by the fact that these impacts are the most up-to-date and reliable impacts.

The impact categories that were identified as relevant contribute together to more than 80% of the total normalized impact of one scenario. This threshold was based on the PEFCR guidance document (European Commission, 2017). Following the PEFCR guidance document, the three toxicity related impact categories – HTCE, HTNCE, and FRTOX – were excluded from the normalization step (European Commission, 2017). This is because the normalization factors in the model behind these impact categories (USEtox model) are not sufficiently robust (Fazio et al., 2018). The impact category IRE was excluded as well since this impact category is not yet fully developed.

A contribution analysis was performed for the impact categories that were identified as most contributing to the total normalized impact. An additional weighting step was not performed since the ILCD method assigns equal weights to all impact categories (European Commission, 2017).

2.4 RESULTS AND DISCUSSION

The objective of this research was to assess the environmental impact and environmental hotspots of different brands and types of canned tuna imports into Aruba. The most relevant impact categories were determined through a normalization step. Then, three comparisons were made. First, the environmental impact of three different brands of canned tuna, originating from Thailand or Peru. Second, the environmental impact of six different accompanying liquids i.e. oils or sauces. Third, the environmental impact of a small (0.142 kg) and a large (1.88 kg) can size.

2.4.1 Normalization and identification relevant impact categories

The most relevant impact categories were identified through external normalization (Table 2-6). Similar values were found for the different comparisons. The environmental impact indicators considered in this study are: climate change (CC), particulate matter (PM), ionizing radiation human health (IRHH), photochemical ozone formation (POF), acidification (AC), terrestrial eutrophication (EUTT), and mineral, fossil & renewable resource depletion (MFRRD). Although climate change was not one of the most contributing impact categories, it was included it in this analysis because of its relevance in today's world.

2.4.2 Environmental impact of different supply chains

The environmental impact of the three different supply chains, based on tuna in vegetable oil in small cans, is depicted in fig. 2-3. The three models show similar results. Being based on the same background data, the differences are resulting from the adaptations in the following life cycle stages: processing, truck transport, and sea transport. The highest environmental impact in all categories was found for Chicken of the sea canned tuna from Thailand. Similar, and slightly lower results were found for Sa-Pac canned tuna from Thailand and Santa Rita canned tuna from Peru.

It stands out that the diesel combustion on the fishing vessel has the same environmental impact for supply chains from Peru and from Thailand: as indicated above, it is part of the background processes that were not adapted (Fig. -2), yet we made the choice to keep it visible in the results so that the processes that were adapted (Processing, Truck transport, and Sea transport) can be appreciated within the larger perspective.

Table 2-6 Contribution per impact category to the total normalized impact of one scenario

Abbreviations are displayed in table 1-3. Abbreviations: sunflower oil (A), soybean oil (B), olive oil (C), tomato sauce (D), brine (E), vegetable oil (F). *Impact categories that together contributed to more than 80% of the total normalized impact. Total normalized impacts may not add up to 100% due to rounding off the values. **The normalization values of the three different supply chains were calculated based on small cans in vegetable oil.

Impact category	Chicken of the sea **	Sa-Pac **	Santa-Rita**	Small can (A)	Small can (B)	Small can (C)	Small can (D)	Small can (E)	Small can (F)	Large can
CC	6%	6%	6%	5%	6%	5%	6%	6%	6%	5%
ODP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM*	10%	10%	10%	10%	10%	10%	10%	10%	10%	9%
IRHH*	10%	10%	11%	12%	11%	11%	14%	12%	11%	11%
POF*	13%	13%	13%	13%	12%	13%	13%	13%	13%	14%
AC*	13%	13%	13%	13%	13%	13%	13%	14%	13%	14%
EUTT*	14%	14%	14%	14%	13%	14%	14%	14%	14%	15%
EUTF	2%	2%	2%	2%	2%	2%	2%	2%	2%	1%
EUTM	9%	7%	7%	9%	7%	7%	7%	7%	7%	8%
LU	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
WD	-1%	-1%	4%	-1%	-1%	4%	0%	-1%	1%	2%
MFRRD*	24%	23%	24%	24%	27%	21%	22%	22%	23%	21%
Total normalized impact:	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total contribution of most relevant impact categories:	85%	84%	84%	86%	86%	82%	86%	86%	84%	83%

For most impact categories, diesel combustion on the fishing vessel is the most contributing life cycle stage. The contribution of diesel combustion is particularly high for AC, EUTT, and POF, compared to other life cycle stages. AC by diesel combustion is caused by the release into the air of acidifying compounds, such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) (EEA, 1995). These acidifying compounds cause EUTT after atmospheric deposition (Rosenbaum et al., 2018). POF by diesel combustion is caused by the emission of non-methane volatile organic compounds (NMVOCs) (Sun et al., 2018). Although NMVOCs are also emitted during metal production and combustion of fuels during sea freight (Siddiqui & Dincer, 2021), these life cycle stages contribute less to the overall particulate ozone formation.

For some impact categories, the contribution of the tin coated steel contributed more than in other impact categories. Namely, for CC, IRHH, PM, and MFRRD. This was mainly due to steel production and not due to the tin. For CC, this was due to the electricity consumption and heat in the production process of steel, because of coal combustion. For IRHH, this was mostly due to electricity consumption, and for PM this was mostly due to the production of heat. IRHH was caused by the production of radionuclides, which have an ionizing potential, during electricity consumption (Frischknecht et al., 2000). To MFRRD, steel consumption contributed for about two third, and tin consumption for about one third. This indicates that tin is scarcer than steel, as a tin can mainly consist of steel. Another contributing life cycle stage to MFRRD was the fishing gear, due to the consumption of minerals including lead.

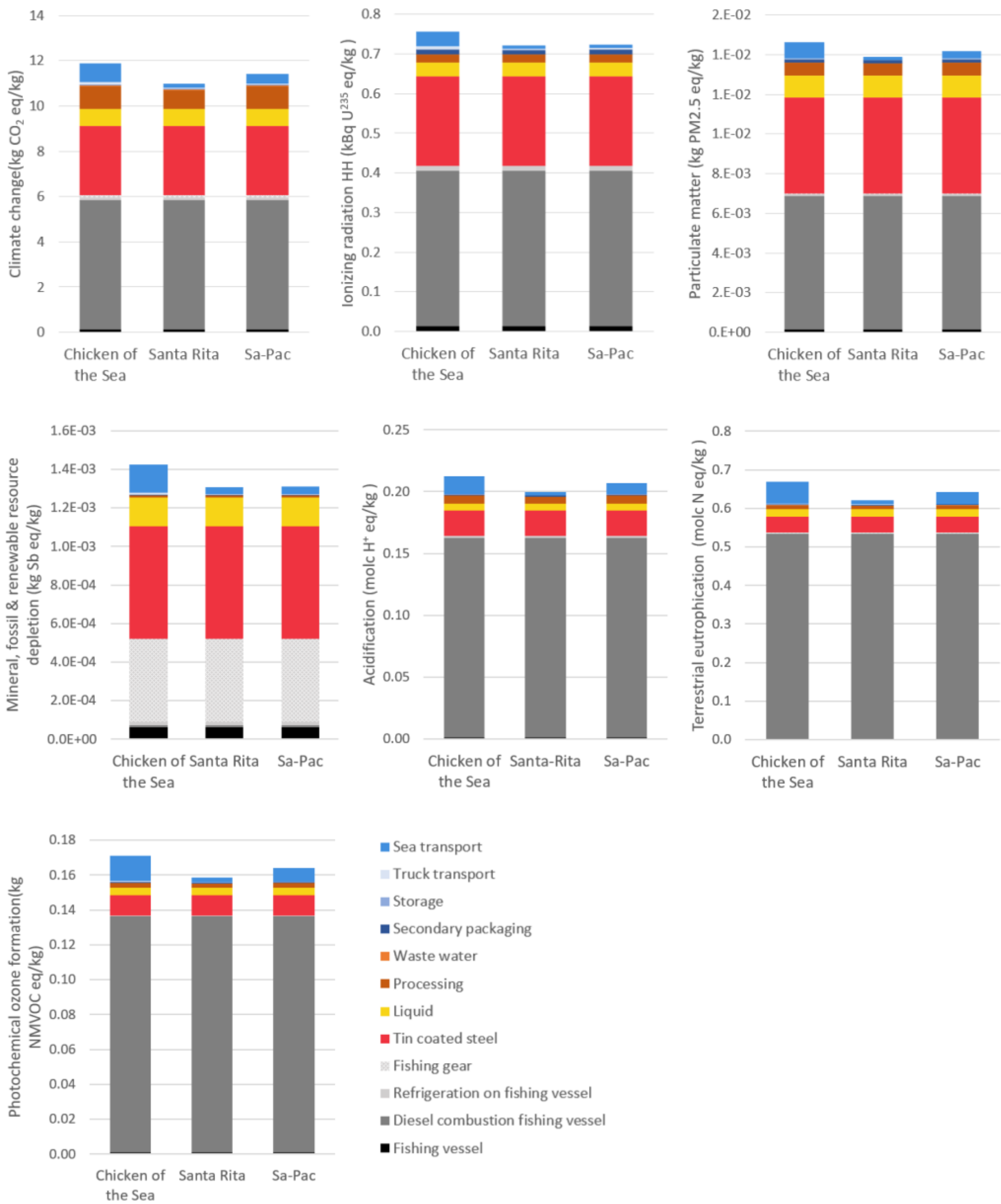

Figure 2-3 Contribution analysis of three canned tuna supply chains

Based on tuna in small cans in vegetable oil. Black and grey bars are related to fishing. Red and yellow bars are related to processing. Blue bars are related to distribution.

Fig. 2-3 further indicates that generally the differences in environmental impact were mainly related to the sea transport and processing, including the tin for the cans. Chicken of the Sea canned tuna consistently had a higher environmental impact due to a longer overseas transport and, even more important, due to the frozen transport step of frozen loins from Thailand to the American cannery (corresponding to 80% of the total overseas transport time). The fact that the transport mode (refrigerated or frozen) matters more is visible when comparing the transport distances between Chicken of the Sea and Santa Rita, with the latter being only less than 4,000 km shorter yet the bright blue being much less visible in fig. 2-3. For Chicken of the Sea, the freezing contributed for 38% - 50% to the environmental impact of sea transport, for most impact categories. For MFRRD and IRHH, freezing contributed even for 75% and 74% to the environmental impact of sea transport, respectively.

As mentioned above, minor differences in the environmental impact of sea transport were observed due to differences in distance sailed. In addition, although different ship sizes were used between transshipments, this did not cause large differences in the environmental impact of sea transport for different supply chains. For all supply chains, most of the sea transport was by relatively large ships. The ship size is measured by its deadweight tonnage (DWT), and mostly a ship with a different size was used between transshipments. For all supply chains, the largest part of the overseas transport (72% - 85%) was by a relatively large container ship, of 120,000 DWT. While for the other transshipments a relatively small ship was used, of 10,000 or 15,000 DWT.

Some adjustments to the original Agribalyse process did not result in major differences between the supply chains. First, secondary packaging was modelled in detail by adding cardboard boxes, pallets, the plastic film around the boxes on the pallet, and transport of the packaging, these did not contribute much to any of the environmental impacts. Second, there was no difference in the contribution of truck transport because the distance covered was similar for the different supply chains. Third, although the electricity during processing was adjusted, there was no difference in the environmental impact of processing between canned tuna from Peru or Thailand. The use of heat during processing often contributed more to the environmental impact of this life cycle stage than electricity, and this was not adjusted.

2.4.3 Environmental impact of different accompanying liquids

Due to the small differences in environmental impact between the different supply chains, as described above, an average supply chain was constructed to compare canned tuna with different accompanying liquids and in different can sizes. For both scenarios, one third was assumed to be Chicken of the Sea, one third Sa-Pac, and one third Santa Rita canned tuna. For the small cans, the following six accompanying liquids were modelled: sunflower oil, soybean oil, olive oil, tomato sauce, vegetable oil, and brine. Results are shown in fig. 2-4. For most accompanying liquids there was only a small difference in environmental impact, as the life cycle stages that contributed most had an identical value: diesel combustion during fishing, and the tin can. However, in some impact categories there were larger differences. First, tuna canned in soybean oil had the highest impact for CC, due to land use change in soybean cultivation. The soybean oil process which was used, 'Soybean oil, at plant/FR U', was a mix of 60.3% Argentina, 20.4% United States, and 19.2% Brazil. Land use change took place in Argentina and Brazil due to the transformation of primary forest into arable land (Nemecek et al., 2016). Second, tuna canned in tomato sauce had the highest impact in the category IRHH. This was due to electricity consumption for cooking of the tomatoes, produced by nuclear power plants in France. Canned tuna in tomato sauce imported into Aruba may have a lower IRHH impact because Peru and Thailand do not rely on energy from nuclear power plants, but mainly on oil and gas, Peru's energy is also for a large part produced by hydropower (BP, 2022). Yet, there is no information on where the tomato sauce was produced and hence the original process remained unchanged. Third, tuna canned in sunflower oil and olive oil had the highest impact for AC and EUTT, due to the farming process and not due to pressing of the sunflowers and olives.

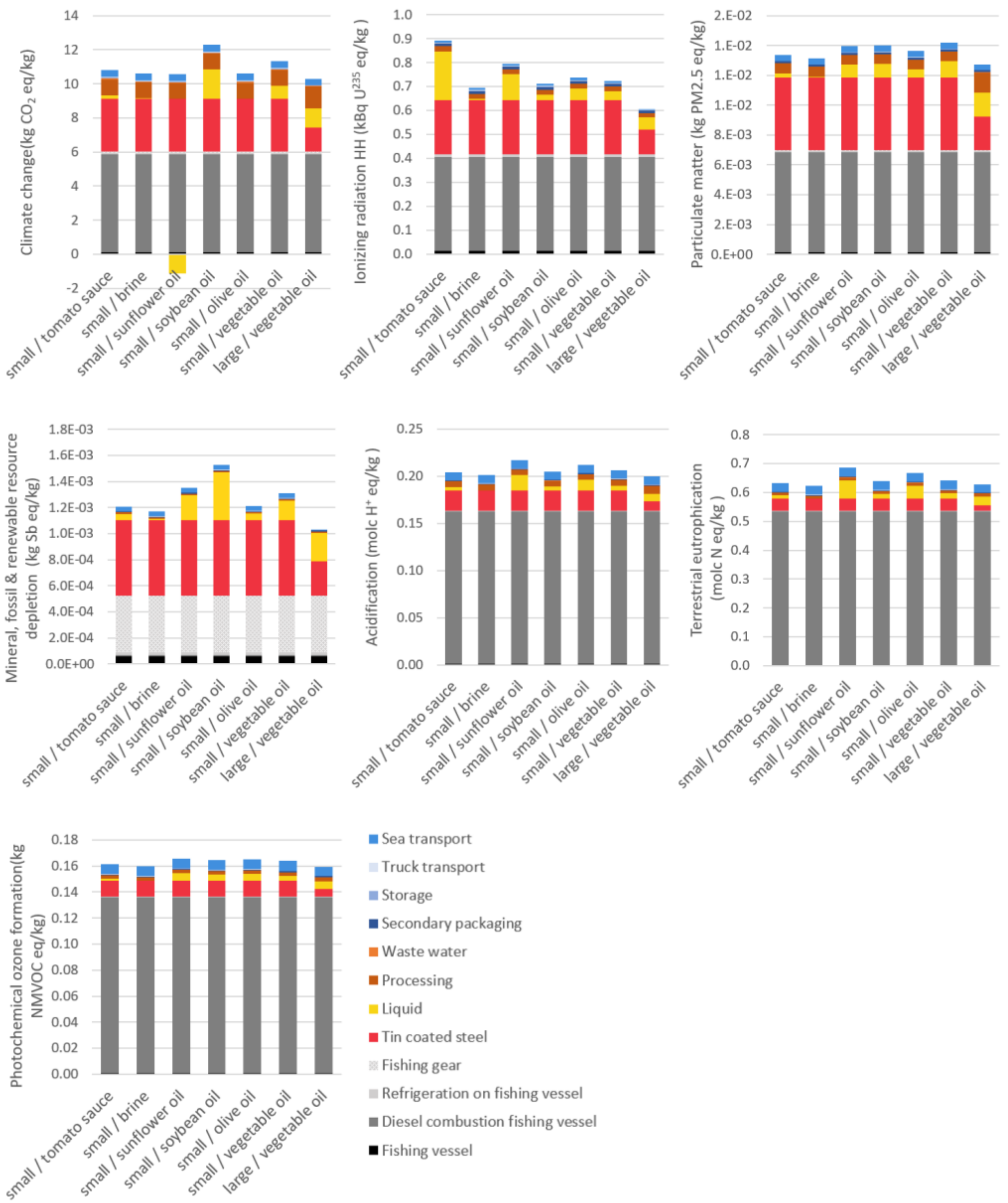

Figure 2-4 Environmental impact of canned tuna in different accompanying liquids and can sizes

Black and grey bars are related to fishing. Red and yellow bars are related to processing. Blue bars are related to distribution.

2.4.4 Environmental impact of different can sizes

A comparison was made between small (142 grams) and large (1.88 kg) canned tuna in vegetable oil (fig. 2-4). Large cans always have a lower environmental impact than small cans. This difference between small and large cans is larger in impact categories where the impact from 'diesel combustion' is overall less dominating, namely CC, IRHH, PM, and MFRRD. For large cans, more vegetable oil and less tin are required, per kg edible tuna, resulting in an overall lower environmental impact. (Avadí et al. (2014) also found that an increase in the amount of edible product per amount of packaging reduces the impact of canned products, per kg product. One of their results showed that the ReCiPe single score of canned anchoveta was 12% lower for a two times larger can size.

Avadí et al. (2015) performed an LCA on three different processed tuna products from Ecuador. The products that were assessed were canned tuna, pouched tuna, and vacuum bagged tuna loins. The latter is a semi-finished product which is exported to canneries abroad. Overall, the main contributors to the products' environmental impact were the fuel use on the fishing vessels and the consumption of packaging material (tin cans in particular). Compared to the other two processed products, the canned tuna product showed the highest impact for all the impact categories assessed in this research (climate change, marine eutrophication, particulate matter formation, metal depletion, cumulative energy demand, marine ecotoxicity, and photochemical oxidant formation).

2.5 CONCLUSION

The objective of this research was to assess and compare the environmental impact and environmental hotspots of different types of canned tuna imported into Aruba. Moreover, the goal was to provide extensive details on the used methods.

Because the observed differences in environmental impact were quite small for most environmental impact indicators, this study can not indicate a preferred canned tuna option unless more data is available about the FUE of specific boats used by different tuna fisheries. However, some trends were observed. First, canned tuna from the Chicken of the Sea supply chain always had the highest environmental impact especially due to a long and for a large part frozen sea transport from Thailand to the US. Preference should be given to local canning activities, close to the landing port. Second, for most accompanying liquids there was only a small difference in environmental impact, as the life cycle stages that contributed most had an identical value: diesel combustion during fishing, and the tin can. Whether it is better to choose for brine in comparison with other accompanying liquids would necessitate an analysis including the subsequent steps, for example, tuna canned in tomato sauce may be part of a meal as such, while tuna canned in brine may be prepared, after opening the can, with another warm or cold sauce, which would lead to additional separate impacts for these sauces. Third, tuna canned in larger cans always had a lower environmental impact compared to tuna canned in smaller cans. Given that all tuna is consumed, large cans are preferred over small cans.

Although the 16 ILCD impact categories were included in this LCA, certain fisheries-specific biologic impacts were not assessed since this was outside the scope of this study. These impacts include for example the potential decrease in stock sizes of target and non-target species and the impact of discharged fishing gear on sea life.

Acknowledgements
The authors would like to thank the SISSTEM team at the University of Aruba, KU Leuven and the European Union (FED/2019/406-549). We acknowledge the wholesalers in Aruba, supermarkets in Aruba, fish outlet in Aruba, and a hotel in Aruba, for their support, knowledge, data, and seafood packaging materials provided. We acknowledge students Brittney Koolman and Mizaira Vrolijk from the Faculty of Arts and Science from the University of Aruba for data collection on canned tuna in supermarkets.

Conflict of interests
All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

CHAPTER 3 THE CARBON FOOTPRINT OF VEGETABLE IMPORTS INTO ARUBA: A CLOSER LOOK AT SEA AND AIR TRANSPORT

Supplementary Materials are available here

This chapter is based on: van Veghel, A. S., Sultan, S., & Geeraerd Ameryckx, A. (2024). The carbon footprint of vegetable imports into Aruba: A closer look at sea and air transport. Future Foods, 10, 100469. https://doi.org/10.1016/j.fufo.2024.100469

CRediT authorship contribution statement
A.S. van Veghel: Conceptualization, Methodology, Formal Analysis, Investigation, Writing – Original Draft, Visualization.

3.1 ABSTRACT

This study aimed to give insights into low-carbon vegetable import strategies for Aruba, a Dutch Caribbean island. Our selected products were potatoes, lettuce, onions, tomatoes, and green beans. The products originated from 13 different countries, and 25 product-country combinations were identified. The system boundaries were from the farm until arrival at the supermarket. We identified actual maritime transport routes, and calculated greenhouse gas (GHG) emissions of passenger aircrafts flying from Amsterdam to Aruba. Vegetables imported by air had significantly higher GHG emissions (4.2–8.3 kg CO_2eq per kg) than products imported by sea (0.4–2.3 kg CO_2eq per kg). GHG emissions of road transport generally contributed more than those of other life cycle stages, except when products showed a high contribution of agriculture. Although sea transport was calculated with much detail, it usually did not contribute much to the GHG emissions. We recommend Life Cycle Practitioners to consider aircraft characteristics when calculating GHG emissions of air transport, and to include the weight of the 80 kg AKE container, used for cooled airfreight, when allocating impacts between passengers and freight. For this case study, GHG emissions of specific passenger aircrafts always resulted in lower GHG emissions compared to generic calculations.

Keywords: Carbon footprint, Vegetable imports, Aruba, Supply chains, Belly freight, Passenger aircrafts

3.2 INTRODUCTION

Increasing the consumption of vegetables is important for human and for planetary health (e.g. Kesse-Guyot et al., 2023; Willett et al., 2019). For planetary health, it is important to gain insight into the environmental impact of vegetables. Many studies have assessed the environmental impact of vegetables, covering different types of vegetables, production methods, and countries of origin (e.g. Frankowska et al., 2019; Michalský & Hooda, 2015; Milà i Canals et al., 2008; Stoessel et al., 2012).

The stages in the supply chain that usually contributed most to the carbon footprint of vegetables were land use change, production at the farm, transport, and losses (Poore & Nemecek, 2018). However, this also differed per country of origin. For example, tomatoes from Benin were found to have a relatively high contribution of greenhouse gas (GHG) emissions from land use change of 3.0 – 7.9 kg CO_2eq per kg, whereas the total GHG emissions of tomatoes from the United States were 0.6 – 0.8 kg CO_2eq per kg (Poore & Nemecek, 2018, appendix: Database). Packaging of food and beverages was usually not one of the main contributing life cycle stages. To further illustrate, Caspers et al. (2023) found that food and beverage packaging makes up 0.3% of the overall carbon footprint of the food consumption of an average German household.

It is interesting that although it is generally stated that transport only contributes about 5-10% to global food system's GHG emissions (IPCC, 2019). Mengyu et al. (2022) recently showed that GHG emissions of food transport might be 3.5 – 7.5 times higher than previously estimated. They indicated that transport accounted for about 19% of total food-system emissions, and for 36% in the case of fruits and vegetables, considering the life cycle stages of production, land use change, and transport. A higher contribution of transport to GHG emissions of vegetables compared to other foods was due to the need of temperature-controlled transportation of vegetables. For some products, similar and higher results were found by Poore & Nemecek (2018, appendix: Database), transport contributed for 49%, 30% and 14% to the categories 'Other vegetables', 'Onions & leeks', and 'Tomatoes', when considering the same life cycle stages as Mengyu et al. (2022). However, when other life cycle stages (Processing, Retail, Packaging, and Losses) were also included, the contribution of transport lowered to 32%, 18%, and 9%, respectively. Thus, it depends on the system boundaries and on the vegetable type how much transport contributed to total GHG emissions.

Among the vegetables with the highest carbon footprint are air freighted vegetables, and vegetables produced in certain types of greenhouses. Casey et al. (2022) found that the carbon footprint of lettuce could vary 51-fold, ranging from 17.8 kg CO_2eq per kg for lettuce produced in a greenhouse with coal as electricity source, to 0.15 kg CO_2eq per kg for field-grown lettuce, from cradle-to-regional distribution centre (RDC). Lettuce that was produced on the field but that was air freighted from the United States to the United Kingdom (8817 km), emitted 10 kg CO_2eq per kg, mainly due to the air freight. Similarly, Milà i Canals et al. (2008) found that green beans air freighted from Kenya or Uganda to the United Kingdom had a carbon footprint of almost 11 kg CO_2eq per kg, whereas green beans produced in the United Kingdom had a carbon footprint of 1.4 – 1.6 kg CO_2eq per kg, from cradle-to-RDC.

In this article, we aimed to give insight into GHG emissions of vegetable imports into Aruba, from cradle-to-retail. Aruba is a small island in the Dutch Caribbean, situated North of Venezuela. The population size is ~110.000 citizens, living on 180 km^2 (The World Bank, 2021). A characteristic of Aruba is the high dependency on tourism. Aruba's hospitality and tourism sector contributed more than 87% to the national GDP (International Monetary Fund. Western Hemisphere Dept., 2019). Aruba's food system shows a near-dependence on imports (Boyer et al., 2020). Most foods are imported to Aruba by sea, although 1.1% of all food is imported by air. Foods imported by air are mainly fresh vegetables (37% of flown-in foods), fresh fish (13%), dairy (13%), and fresh fruits (12%). Of all vegetables, 3% is imported by air (own calculations from data CBS Aruba, personal communication, March 11, 2021).

As mentioned above, air freighted vegetables are among those with the highest GHG emissions. However, in all studies known to the authors, GHG emissions of air transport were modelled using a generic approach, which did not consider the aircraft models used. Research using such a generic approach are Casey et al. (2022); Frankowska et al. (2019); Mengyu et al. (2022); Milà i Canals et al. (2008); Stoessel et al. (2012). It was not always clear whether the selected process was based on a passenger aircraft, a cargo aircraft, or a combination of both. Nearly all food products imported into Aruba by air were imported with passenger aircrafts, which is common for many tourist destinations, and especially for island destinations (Button, 2021). However, GHG emissions can be different when using different types of passenger aircrafts. Davydenko et al. (2020) calculated GHG emissions of transporting cargo shipped on passenger aircrafts, referred to as belly freight, were 0.41 – 0.77 kg CO2eq per tonne kilometre (tkm), depending on the aircraft type and distance covered. Globally, half of all air cargo is shipped by passenger aircrafts, and shipping air cargo in passenger aircrafts has increased in times of higher oil prices and fiercer competition between airlines (Bilotkach, 2021). The lack of calculating GHG emissions of transporting cargo by passenger aircraft is an important gap in the literature of Life Cycle Assessments (LCA) associated with the food chain. Also, the difference in GHG emissions of different types of aircrafts can be important as well.

Another important aspect of Aruba's food chains is the dependency on sea transport, while not being situated on main maritime transport routes. Therefore, actual sea transport routes and types of ships used were determined in detail. This is not a mainstream approach, as most LCA practitioners use sea distance calculators and do not take into account the types of ships used (e.g., Frankowska et al., 2019; Pérez-Neira et al., 2020; Takacs et al., 2022). Other authors base sea transport distances on local documents (e.g., Bell & Horvath, 2020) or on data provided by importing companies (e.g., Goossens et al., 2019).

To study the transport routes of vegetable imports into Aruba we started from the extensive database of the carbon footprint of vegetables from Poore & Nemecek (2018) (cradle-to-retail) which contains data of 570 different agricultural studies, through a unified methodology. We then collected data on transport routes (road, air, sea) for importing vegetables into Aruba. Overall, we aimed to get insight into the carbon footprint of vegetable imports into Aruba, with emphasis on modelling GHG emissions of belly freight, and actual maritime transport routes. Our focus was on case studies of a selection of vegetables.

3.3 METHODS

LCA was used to calculate the carbon footprint, also known as the environmental impact indicator climate change or global warming, according to the ISO 14040 standard.

In this study, three innovations were introduced to calculate the GHG emissions of vegetable imports. First, actual maritime transport routes and ship characteristics were modelled. Second, GHG emissions of the specific passenger aircrafts that were actually flying from Amsterdam to Aruba were modelled. Third, the weight of the 80 kg specialized AKE container for cooled airfreighting was included in the model.

3.3.1 Selection of vegetables

Vegetables were selected by their weight contribution to the total vegetable category in Trade Map import statistics from 2017 – 2019 (International Trade Center, 2020), potatoes were included in this category. This timeframe was selected to represent pre-covid vegetable import levels, as Aruba was highly impacted by the pandemic, and more recent data might not reflect current vegetable consumption patterns. The most imported vegetables into Aruba were selected: potatoes (18.5 weight%), lettuce (10 wt%), onions (10 wt%), and tomatoes (8.5 wt%). Green beans were also selected as an interesting case study; these can be flown in from Kenya via the Netherlands or shipped to Aruba by sea from the United States. The import quantity of green beans was not available, as green beans were grouped together with other vegetables in the trade statistics. In total, a minimum of 47 wt% of vegetable imports were included in this analysis.

For all five products, the countries of origin were determined via Trade Map and by visiting supermarkets in Aruba. In May 2022, nine different-sized supermarkets across Aruba were visited three times during three weeks. Additional product-country combinations, that were not identified via Trade Map, were discovered through the supermarket visits. Table S1 in the Online Supplementary Materials shows the countries of origin per product and whether the origin was identified via Trade Map, via the supermarket, or both. To identify the countries of origin, it was important to use both Trade Map data and to visit supermarkets, as explained in section 1.1 of the Online Supplementary Materials. Thirteen countries of origin and 25 product-country combinations were identified (fig. 3-1).

3.3.2 Goal and scope definition

This study explored the carbon footprint of vegetable imports into Aruba, with a focus on transportation by air, and sea. The system boundaries ranged from farm in country of origin until arrival at the supermarket in Aruba (fig. 3-1). The system boundaries included agriculture (including land use change), processing, packaging, losses (post-harvest and distribution) and chilled road/sea/air transport. Fig. 3-1 also mentions further parameters (such as distance and time) on the supply chain per vegetable and country combination. The functional unit of this study was 1 kg packaged product at the supermarket in Aruba.

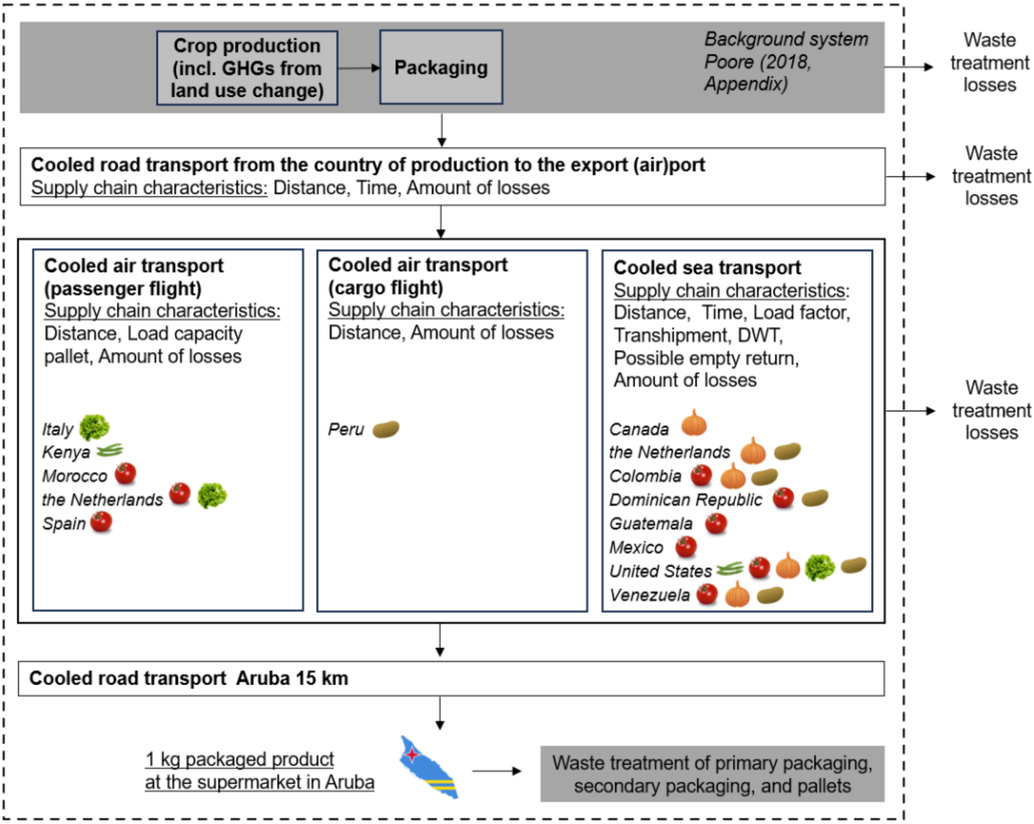

Figure 3-1 System boundaries and supply chain characteristics

Dark grey boxes used background systems from Poore & Nemecek (2018). Processes outside the dotted box were excluded.

3.3.3 Supply chain description and inventory data

The supply chains are depicted in fig. 3-1. Three different LCA databases were used: the meta-analysis "LCA of food & drink products" from Poore & Nemecek (2018) as the basis, Agri-footprint version 4.0 for data on sea transport, and ecoinvent (version 3.3) for data on road transport and air transport. Following Poore & Nemecek (2018), the characterization method IPCC 2013 GWP 100a was used. Details on these processes are displayed in the Online Supplementary Materials (section 1.2).

After harvest, postharvest losses occurred, and products were packaged. Then, products were transported to the harbour or airport. Products from Mexico, Guatemala, Canada, and the United States were transported by truck to port Everglades in the United States. Onions and potatoes from the Netherlands were trucked to the port of Rotterdam. Products from Colombia were trucked to the port of Barranquilla or Cartagena; it was assumed that both ports were used equally frequently. Products from the Dominican Republic were assumed to be trucked to the port of Caucedo. Tomatoes from Morocco required additional sea transport between Tanger (Morocco) and Algeciras (Spain). Sea transport distances and durations are shown in the right columns of table 3-1. After sea transport or air transport of the products to Aruba, 15 km of cooled road transport occurred in Aruba (Aruba's dimensions are 32 x 10 km on 180 km^2).

Some products were transported directly to Aruba, while transshipment occurred for other products. Onions and potatoes from the Netherlands were shipped to Aruba via Jamaica. Products from Colombia and the Dominican Republic were shipped directly to Aruba. All other products imported by sea were shipped via port Everglades in Florida. Potatoes from Peru were flown in directly via a small cargo plane. Other products imported by air were flown in from Amsterdam (the Netherlands), with passenger aircrafts. Green beans from Kenya required additional air transport from Kenya to the Netherlands.

Table 3-1 Characteristics of agricultural data and transport data for product-country combinations

*Abbreviations for proxies: Colombia (CO), Peru (PE), Spain (ES), United Kingdom (UK), and the United States (US). **The location of the farm was determined by four different approaches or a combination of these, with the preference ranging from A to D, based on the appendix of Poore & Nemecek (2018). A: Geographic specification, B: Geographic specification of the same product, C: Geographic specification of similar products, D: Centre of country. ***Numbers between brackets represent an average.

Country	**Product**	**Proxies ***	***Farm* Data points (n) ****	***Farm* Method for location**	**Road transport (km)**	**Cooling road transport (days)**	**Sea transport (km)**	**Cooling sea transport (days)**	**Air transport (km)**
Canada	Onions	US	1	C	2252 – 4829 (4685)***	0.9 – 1.9 (1.6)***	2330	6	n.a.
Colombia	Tomatoes	n.a.	1	B	989 – 1045 (1017)	0.6 – 0.7 (0.7)	1174	5	n.a.
	Onions	US	1	C	989 – 1045 (1017)	0.6 – 0.7 (0.7)	1174	5	n.a.
	Potatoes	PE	1	C	989 – 1045 (1017)	0.6 – 0.7 (0.7)	1174	5	n.a.
Dominican Republic	Tomatoes	CO	1	D	139	0.1	2287 – 2303 (2300)	10	n.a.
	Potatoes	PE	1	D	139	0.1	2287 – 2303 (2300)	10	n.a.
Guatemala	Tomatoes	CO	1	D	4328	2	2330	6	n.a.
Italy	Lettuce	n.a.	3	A	1121 – 1294 (1236)	0.5 – 0.6 (0.5)	n.a.	n.a.	7872
Kenya	Green beans	n.a.	1	C	33 – 41 (37)	0.0	n.a.	n.a.	14534
Mexico	Tomatoes	US	6	C	3360 – 3513 (3404)	1.4 – 1.5 (1.4)	2330	6	n.a.

Table continues on next page

Country	Product	Proxies *	*Farm* Data points (n) **	*Farm* Method for location	Road transport (km)	Cooling road transport (days)	Sea transport (km)	Cooling sea transport (days)	Air transport (km)
Morocco	Tomatoes	n.a.	1	A	3278	1.3	31	0	7872
Netherlands	Tomatoes	n.a.	8	2xA 6xB	57 – 64 (61)	0.0	n.a.	n.a.	7872
	Onions	n.a.	3	C	76	0.0	10901	30	n.a.
	Lettuce	n.a.	2	C	76	0.0	n.a.	n.a.	7872
	Potatoes	n.a.	5	1xA 4xB	61	0.0	10901	30	n.a.
Peru	Potatoes	n.a.	2	A	69 – 1307 (688)	0.1 – 0.9 (0.5)	n.a.	n.a.	2823
Spain	Tomatoes	n.a.	15	14xA 1xB	1507 – 2315 (1866)	0.6 – 0.9 (0.7)	n.a.	n.a.	7872
United States	Green beans	ES, UK	5	C	266 – 5161 (3828)	0.1 – 2.0 (1.5)	2330	6	n.a.
	Tomatoes	n.a.	6	A	266 – 4595 (2804)	0.1 – 2.0 (1.0)	2330	6	n.a.
	Onions	n.a.	1	A	4775	1.8	2330	6	n.a.
	Lettuce	n.a.	4	A	4352	1.6	2330	6	n.a.
	Potatoes	n.a.	2	1xA 1xB	5161	2.0	2330	6	n.a.
Venezuela	Tomatoes	CO	1	D	757	0.6	120 – 157 (139)***	0.3 – 0.4 (0.4)***	n.a.
	Onions	US	1	D	757	0.6	120 – 157 (139)	0.3 – 0.4 (0.4)	n.a.
	Potatoes	PE	2	D	757	0.6	120 – 157 (139)	0.3 – 0.4 (0.4)	n.a.

Agriculture and processing

GHG emissions from agriculture and processing were selected from Poore & Nemecek (2018, appendix: Database). When data from a specific country of origin was not available, data points of all neighbouring or the most nearby countries were selected as proxies. For example, as visible in the first row of table 3-1, there was no data on onions from Canada and data from the United States was used as a proxy. For the majority of the data information from the country of origin actually was available (column proxy is then marked by n.a. in table 3-1). Data points selected for this analysis ranged from 2006 – 2015. For some product-country combinations several data points were available. In these cases a weighted average was calculated, based on the representativeness of a data point as determined by Poore & Nemecek (2018, appendix: Database). The likelihood of specific production methods (for example, organic vs non-organic) occurring for a product-country combination was included in these weights.

Losses

Losses were determined based on the country of origin (not on the proxies). Losses were estimated for post-harvest handling, processing, and for distribution. Losses during processing were only included for lettuce from Italy (Poore & Nemecek, 2018, appendix: Database), and were 2% (Gustavsson et al., 2013). Losses from post-harvest handling and distribution are shown in table 3-2.

Post-harvest losses were assumed to occur at the farm, to incorporate the weight of the losses into the calculations. It was assumed that products were packaged afterwards. Packaging of the losses was accounted for. End-of-life treatment of losses was not included (fig. 3-1). To determine the quantity of post-harvest losses an average of 2009-2011 from FAOSTAT was used, as provided by Poore & Nemecek (2018, appendix: Standardisation). The FAOSTAT data categories on losses during distribution exactly matched for potatoes and tomatoes. The losses for onions, lettuce, and green beans were matched with the FAOSTAT categories ‘onions and leeks’, ‘other vegetables’, and ‘other vegetables’, respectively.

Losses during distribution were available in aggregated form per continent, based on data from Annex 1 in Gustavsson et al. (2013), as provided in Poore & Nemecek (2018, appendix: Standardisation). This data was based on the FAO Food Balance

Sheets from 2007 and additional resources. Additional resources used for products in this study ranged from the years 2001 – 2011. Losses during distribution of potatoes were matched with FAO's category 'roots and tubers', whereas losses for all other products were matched with the FAO category 'fruit and vegetables'. It was assumed that half of the losses during distribution occurred during road transport and half of the losses during sea or air transport.

Table 3-2 Supply chain losses (post-harvest, distribution)

Based on Poore & Nemecek (2018, appendix: Database). Abbreviations: Canada (CA), Colombia (CO), Dominican Republic (DO), Spain (ES), Guatemala (GT), Italy (IT), Kenya (KE), Morocco (MA), Mexico (MX), the Netherlands (NL), Peru (PE), South and Central America and the Caribbean (SCAC), United States (US), and Venezuela (VE).

Product	**Post-harvest losses** Poore & Nemecek (2018, appendix: Standardisation)		**Losses during distribution** (Gustavsson et al., 2013)
Potatoes	NL: 1.9% US: 4.1% DO: 10.2% CO: 11.5% PE: 21.8%		SCAC* (CO, DO, PE): 3% Europe (NL): 7% Northern America (US): 7%
Onions	NL: 2.7% CA: 4.7% US: 5.0% VE: 12.0% CO: 18.6%		Europe (NL): 10% Northern America (CA, US): 12% SCAC* (CO, VE): 12%
Lettuce	NL: 3.1% US: 5.3% IT: 10.8%		Europe (IT, NL): 10% Northern America (US): 12%
Tomatoes	VE: 2.2% CO: 3.8% MX: 4.0% NL: 4.0% ES: 4.3%	US: 5% MA: 7.8% DO: 9.9% GT: 10.9% VE: 13.0%	Europe (ES, NL): 10% SCAC (CO, DO, GT, MX): 12% Northern America (US): 12% Africa (MA): 15%
Green beans	KE: 4.7% US: 5.3%		Northern America (US): 12% Africa (KE): 17%

Consumer packaging and packaging for transportation

It was assumed that all products were packaged at the farm and that the packaging materials remained the same throughout the supply chain. Next to primary (direct package) and secondary (boxes) packaging, also a pallet (wooden or foam), and plastic film around the pallet were included. Foam pallets were only used for products imported by air. Air freighted products were more often transported on wooden than on foam pallets, therefore the weight of foam pallets were not included in our analysis. For products flown in by large aircrafts, the 80 kg AKE container that entered the aircraft was also included. All flown-in products except for potatoes from Peru arrived in large aircrafts and in an AKE container. Transport of the weight of the packaging materials (Table 3-3) was included in the GHG emissions calculations for transport. The carbon footprint of the packaging was copied directly from Poore & Nemecek (2018, appendix: Packaging).

Products could be transported either on wooden or on foam pallets. Wooden pallets were used more often and were discarded after use (Superfood, personal communication, October 2, 2023). Different types of wooden pallets were used, the average weight of a wooden pallet was 21.9 kg, based on 7 measurements (own measurements). Foam pallets weighed 3.1 kg. All vegetables were mixed on one pallet, except for tomatoes which were imported per pallet (Superfood, personal communication, August 18, 2023). The plastic film around a pallet weighed 640 grams (De Vlieghere et al., 2023). The amount of product per pallet was 435 kg for tomatoes, and on average 631 kg for other products (Center for Environmental Farming Systems, 2016).

Flown-in products were transported in AKE lower-deck containers (J. Janssen, personal communication, April 10, 2023), a type of Unit Load Device (ULD) that weighed 80 kg (Freja, 2023; PalNet GmbH Air Cargo Products, 2023; VRR, n.d.). Although the (International Air Transport Association, 2022a) recommended excluding ULDs in the calculation of GHG emissions of air freight, the authors decided to include the weight of the ULDs. Because additional infrastructure for transporting passengers is also included when allocating GHG emissions between cargo and passengers, and the absence or presence of ULDs influences the actual cargo capacity available for the products, which in turn influences the amount of GHG emissions allocated to cargo.

Table 3-3 Weight of packaging materials

For products with a (*) there was no data available about primary and secondary packaging in Davis et al. (2011), an average was calculated based on all vegetables. Products with a (**) were imported on pallets mixed with other products, therefore an average was calculated.

Product	**Primary packaging (g / kg product)**	**Secondary packaging (g / kg product)**	**Wooden pallet (g / kg product)**	**Foam pallet (g / kg product)**	**Plastic film (g / kg product)**	**AKE container (g / kg product)**	**Total packaging (g / kg product)**	
							Wooden pallet	**Foam pallet**
Potatoes	6*	13*	35**	n.a.	1.0**	130**	184	n.a.
Onions	6*	2	35**	n.a.	1.0**	130**	173	n.a.
Lettuce	7	8	35**	4.9**	1.0**	130**	180	145
Tomatoes	6	6	49	6.8**	1.4	180	240	192
Green beans	6*	12*	35**	4.9**	1.0**	130**	183	148
References	Table 9 from Davis et al. (2011)	Table 11 from Davis et al. (2011)	See section 2.4.3	See section 2.4.3	See section 2.4.3	See section 2.4.3	See section 2.4.3	See section 2.4.3

Road transport

The distance by road was based on the fastest route in Google Maps. The locations of the farms were based on (Poore & Nemecek, 2018, appendix: Database), using four different approaches or a combination of these, as shown in table 3-1. With the preference ranging from A to D, with A: Geographic specification, B: Geographic specification of the same product, C: Geographic specification of similar products, D: Centre of country. It was assumed that all countries used cooled road transport. For calculating road transport, we deviated from the methodology of Poore & Nemecek (2018) because road transport and cooling of road transport were major contributing processes during one of our iterations (Online Supplementary Materials - section 1.3). Cooled road transport in Aruba was assumed to be 15 km.

Sea transport

Sea transport was mostly determined via the schedule of CMA CGM, one of the largest container shipping companies (AXSMarine, 2022). Their schedule showed duration, place(s) of transshipment, shipping lines, and vessel names (CMA CGM, 2022b). Data on distances between ports was obtained via the CMA CGM Eco Calculator (CMA CGM, 2022a). Data on the size of the ships was obtained via www.marinetraffic.com, expressed as summer deadweight tonnage (DWT). Often at least one transshipment was required to import products to Aruba. The size of the container ships used on different routes could differ. Smaller container ships were often used for the last transshipment to Barcadera, the port in Aruba. It was assumed that larger container ships (> 13,000 DWT) were sailing at a load factor of 100%, and smaller container ships, used for the last transshipment to Aruba, at a load factor of 80%. For these smaller ships an “empty return” was assumed, as Aruba has very limited exports (OEC, 2024). The transport routes from Cartagena and Barranquilla in Colombia were based on a schedule from Caribbean Feeder Services (2022). GHG emissions were determined using the Agri-footprint v4.0 database with economic allocation and were based on the characteristics DWT, load factor, distance sailed, and possible empty return. GHG emissions of cooling were included, to account for cooling of the container before and after the shipment, one additional day was added to the transit time.

Products from Venezuela were transported on smaller cargo boats with a capacity of 40 to 60 tonnes (ABC Online Media, 2023), either the Gaviota II or the El Maracucho (The Daily Herald, 2023). The boats departed from Venezuela either from the port las Piedras or from the port of Coro, which were between 65 and 85 nautical miles (120 – 157 km) away from Aruba (Harbor master Aruba, personal communication, August 7, 2023). The ships sailed back empty. It was assumed that 1000 L diesel was used in total for 50 tonnes of products (personal communication, marine expert Aruba, September 28, 2023).

Air transport

GHG emissions from air transport were calculated using three different approaches, of which one for a small cargo aircraft, and two for large aircrafts. First, carbon emissions of a small cargo aircraft were modelled only for potatoes from Peru. Second, for a generic approach for large aircrafts we used the GHG emissions as displayed in Poore & Nemecek (2018). Third, for a specific approach for large aircrafts we calculated GHG emissions of passenger aircrafts from the airline KLM flying from Amsterdam to Aruba, with primary data.

All flight distances were determined with www.airmilescalculator.com and 125 km was added to correct for excess distance due to stacking, traffic, and weather-driven conditions (ICAO, 2018). Small cargo aircrafts emitted 0.86 kg CO_2eq per tkm (SimaPro LCA software). Poore & Nemecek (2018) assigned 1.13 kg CO_2eq per tkm and assumed no additional cooling. Recent articles also used 1.1 kg CO_2eq per tkm for intercontinental air transport, based on a process from the ecoinvent LCA database (e.g., Casey et al., 2022; Mengyu et al., 2022; Stoessel et al., 2012). Calculations of GHG emissions of belly freight are explained in the following paragraphs.

Belly freight calculations

GHG emissions of belly freight were calculated based on an ecoinvent process for long haul intercontinental air transport. This process included airport construction, aircraft construction, cooling, kerosene, and burning of kerosene. The process was adjusted in three ways. First, by calculating the amount of kerosene used and burned. Second, by adding engine oil, as synthetic oil was used in aircraft engines (Federal Aviation Administration, 2013). Third, by allocating the total GHG emissions between passengers and cargo. This will be explained in the following paragraphs.

Kerosene

Kerosene use was dependent on the aircraft type and flight distance. The most used passenger aircrafts were the Airbus A330-203 and the Airbus A330-303. The Airbus A330-303 arrived in Aruba most frequently, the Airbus A330-203 arrived twice a week (personal communication station manager KLM in Aruba, E. Croes, April 21, 2023). Table 3-4 depicts the characteristics of both aircraft types. The Airbus A330-303 had a higher cargo capacity, a higher passenger capacity, and less range than the Airbus A330-203.

Table 3-4 Characteristics of Airbus A330-203 and Airbus A330-303

	Airbus A330-203	**Airbus A330-303**	**Source**
Empty operating weight (EOW)	121 tonnes	121 tonnes	(Aircraft Commerce, 2008)
Passenger capacity	248	292	(SkyTeam Virtual, 2023a, 2023b)
Cargo capacity	18.7 tonnes	21.2 tonnes	(SkyTeam Virtual, 2023a, 2023b)
Range	13,427 km	11,760 km	(SkyTeam Virtual, 2023a, 2023b)
Maximum Landing Weight (MLW)	182 tonnes	187 tonnes	(European Union Aviation Safety Agency, 2023; SkyTeam Virtual, 2023a, 2023b)
Maximum Take-off weight (MTOW)	242 tonnes	242 tonnes	(European Union Aviation Safety Agency, 2023; SkyTeam Virtual, 2023a, 2023b)
Maximum Zero Fuel Weight (MZFW)	170 tonnes	175 tonnes	(European Union Aviation Safety Agency, 2023; SkyTeam Virtual, 2023a, 2023b)

GHG emissions of burning kerosene were calculated in three steps. First, the flight distance was calculated. The great circle distance (GCD) from Amsterdam to Aruba was 7883 km (www.airmilescalculator.com). Second, fuel use was calculated based on the corrected GCD, as explained above. For the Airbus A330-203 and the Airbus A330-303 the fuel use was 55,079 kg and 56,587 kg, respectively (ICAO, 2022). Third, GHG emissions from burning fuel were calculated by multiplying the fuel use by the fuel conversion factor 3.16 kg CO_2eq per kg, which is an accepted standard in the field (Graver et al., 2019; ICAO, 2018; International Air Transport Association, 2022a).

Engine oil

Oil use ranged from 0.53 – 0.82 L per engine per hour. It was recommended to assume an oil use of 0.82 L (J. Jansen, personal communication, April 19, 2023). The block time for a flight from Amsterdam to Aruba was 10 hours. Therefore, the oil use of two engines during this flight was 16.4 L.

cargo:passenger allocation

Total GHG emissions were allocated to the cargo and the passengers by an allocation factor, based on the methodology of the International Civil Aviation Organization (ICAO) (ICAO, 2018), a United Nations Agency. Other authors also used this method (Davydenko et al., 2020; Graver et al., 2019; International Air Transport Association, 2022b; A. Klein et al., 2021). Perishable cargo was transported in Unit Load Devices (ULDs), which are one pallet-sized containers shaped to fit in a plane.

Allocation to cargo was calculated at different cargo capacity utilization rates. Because no data was available on cargo capacity utilization, and this may differ from flight to flight. The following formula was used to calculate the allocation factor to cargo:

$$\frac{Cargo\ (kg)}{Cargo\ (kg) + No.Passenges \times 100kg + No.of\ seats \times 50kg}$$

In the above formula, 100 kg represented the average passenger mass with baggage, and 50 kg accounted for the on-board equipment and infrastructure associated with passenger use (ICAO, 2018). This included the seats, toilets, catering, and service staff and was included also when the seat was not occupied. The number of passengers was calculated based on the average passenger utilization of the airline KLM for flights to the Caribbean. This was 90% from 2016 – 2019 (KLM, 2017, 2019).

The maximum cargo capacity was calculated at different utilization factors. The maximum cargo capacity was calculated by subtracting the luggage weight from the cargo capacity, based on a luggage weight of 23 kg per passenger. The maximum cargo capacity was 13,591 and 15,151 tonnes for the A330-203 and A330-303, respectively. At these maximum cargo capacities, freight allocation was calculated, as shown in table 3-5.

Table 3-5 Allocation of GHG emissions to cargo (including product, packaging, and transport infrastructure)

	Airbus A330-203		**Airbus A330-303**	
Cargo capacity utilization	**Cargo quantity (tonnes)**	**Allocated GHG emissions to cargo**	**Cargo quantity (tonnes)**	**Allocated GHG emissions to cargo**
0.01%	0.01	0.04%	0.02	0.03%
10%	1.4	4%	1.5	3%
20%	2.7	7%	3.0	6%
30%	4.1	11%	4.5	9%
40%	5.4	14%	6.1	12%
50%	6.8	16%	7.6	14%
60%	8.2	19%	9.1	17%
70%	9.5	22%	10.6	19%
80%	10.9	24%	12.1	21%
90%	12.2	26%	13.6	23%
100%	13.6	28%	15.2	25%

3.4 RESULTS AND DISCUSSION

First, the results from our calculations on GHG emissions from air transport are shown. These results will assist in interpreting the subsequent results. Second, we present an overview of GHG emissions of vegetable imports into Aruba. Finally, we discuss our recommendations for future research on low-GHG emissions import strategies for vegetable imports to Aruba. All the absolute values used to create the graphs are available in the Online Supplementary Materials (Excel).

3.4.1 Air transport

Belly freight

In this section, the GHG emissions of calculating GHG emissions of air transport using a specific approach, are discussed and compared to using a generic approach (Fig. 3-2). GHG emissions calculated with a generic approach were about 1.6 – 2.5 times higher compared to specific passenger aircrafts. For example, GHG emissions of the passenger aircraft A330-303 at 100% cargo capacity utilization are 2.5 times lower than when using a generic approach. It was assumed that the ecoinvent version 3.3 process used by Poore & Nemecek (2018) was “market for transport, freight, aircraft“. This process was based on passenger jets flying a distance of 6000 km, a cargo capacity utilization was not mentioned. It could be that our calculations show lower GHG emissions per tkm due to a longer flight distance of 8008 km, since fuel use per tkm decreases upon longer transport distances (Davydenko et al., 2020).

The weight of packaging and of the AKE container contributed for about 15% to total GHG emissions when using a generic approach, mostly due to the weight of the AKE container. Therefore, we recommend LCA practitioners to include the weight of the 80 kg AKE container in their LCA’s.

GHG emissions from the A330-203 aircraft were higher compared to the A330-303 aircraft. This was probably because the A330-203 had a lower cargo and passenger capacity than the A330-303, while both aircrafts had the same weight. Thus, more fuel was used per kg of product, and fuel contributed most to total GHG emissions. To a lesser extent, GHG emissions were due to transport of the AKE container. Other life cycle stages (airport production, aircraft production, engine oil, cooling, and packaging) contributed very little to total GHG emissions. Although airport and aircraft production emitted GHG emissions, due to the lifespan and the allocation of GHG emissions among all products transported during their lifespan, GHG emissions per kg product were relatively low.

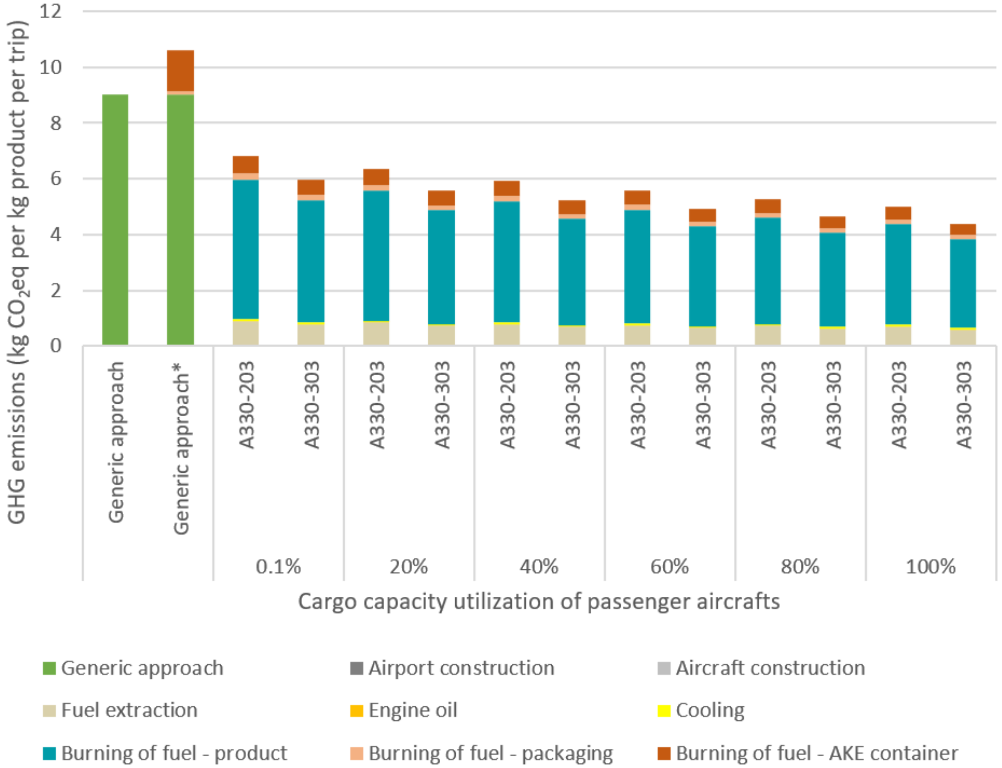

Figure 3-2 GHG emissions of air transport of 1 kg packaged product, from Amsterdam to Aruba (8008 km)

Calculated using a generic approach and for specific passenger aircrafts A330-203 and A330-303 at different cargo capacity utilization rates ranging from 0.1% to 100% (specific approach). *Results from the generic approach are shown with and without the weight of packaging and the AKE container.

The results of burning fuel to transport the product (without packaging and the AKE container) were comparable to those of Davydenko et al. (2020), who calculated GHG emissions of belly freight in passenger aircrafts with different characteristics. They calculated GHG emissions of belly freight for a trip from Shanghai to Amsterdam (11 hours and 20 minutes), in three different types of passenger aircrafts. They assumed a cargo capacity utilization of 80%, which resulted in GHG emissions of 0.50, 0.59, and 0.77 kg CO_2eq per tkm, dependent on several aircraft characteristics. Whereas our calculations resulted in 0.42 and

0.48 kg CO_2eq per tkm, for transporting only the product, for a 10 hour flight. Our results were probably lower due to a lower empty operating weight (EOW) of 121 tonnes, whereas aircrafts in the study of Davydenko et al. (2020) had an EOW of 145 or 186 tonnes. Another difference between the aircrafts was the passenger capacity. Aircrafts in our study could transport a maximum of 248 or 292 passengers. Aircrafts in the study of Davydenko et al. (2020) could transport a maximum of 275, 320, or 408 passengers.

The above example showed the variability of GHG emissions of cargo transported by passenger aircrafts, due to different characteristics such as the trip length, EOW, and number of passengers. Additionally, the volume restriction of an aircraft should be considered, as the values calculated for this research cannot be copied directly. For example, a plane filled to the maximum capacity with only flowers, a product with a low weight to volume ratio, will not reach the maximum weight capacity of the aircraft. This would result in higher GHG emissions per kg flowers.

Also, GHG emissions were based on a direct flight from Amsterdam to Aruba. Currently, there was always a direct flight, but the flight schedule may change every six months (Air cargo specialist, personal communication, January 27, 2022). Direct flights are not the case for all (Dutch Caribbean) islands. For example, flights from Amsterdam to Bonaire may navigate via Aruba. A stopover would increase GHG emissions due to another take-off and landing.

Although it is known that GHG emitted in high altitude have specific effects, expressed by the radiative forcing index, this was not included in this research due to a lack of scientific consensus (Graver et al., 2019; International Air Transport Association, 2022b; Jungbluth & Meili, 2019).

Contribution of air transport to GHG emissions of vegetable imports

GHG emissions of all flown-in products are shown in fig. 3-3. In the next section the GHG emissions of products that were not flown in will also be shown. To show the differences between methodologies, results are shown calculated by the methodology of Poore & Nemecek (2018), and by the methodology for passenger aircrafts described in this article. Also, for potatoes from Peru the results from selecting the process for a small cargo aircraft are shown. The solid yellow bar depicts the minimum GHG emissions of using a passenger aircraft, whereas the sum of the solid and transparent yellow bar indicates the maximum GHG emissions of using a passenger aircraft. Minimum GHG emissions were calculated at 100% cargo capacity utilization of an A330-303 aircraft. Maximum GHG emissions were calculated at 0.1% cargo capacity utilization of an A330-203 aircraft. Two different aircraft types were used because the A330-203 aircraft always had higher GHG emissions (Fig. 3-2).

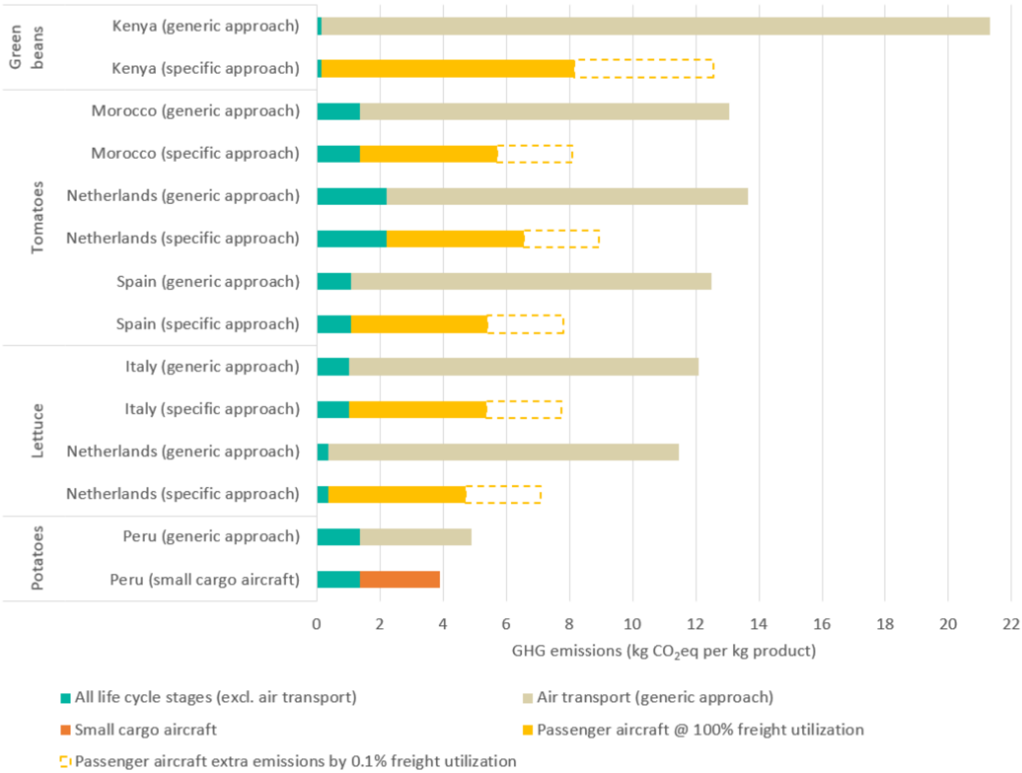

Figure 3-3 GHG emissions of flown-in products, based on a generic approach and on specific aircraft characteristics for passenger aircrafts

The solid yellow bars show GHG emissions of passenger aircrafts at 100% cargo capacity utilization (Airbus A330-303). The sum of the solid and transparent yellow bars show GHG emissions of passenger aircrafts at 0.1% cargo capacity utilization (Airbus A330-203).

It stands out that for all flown-in products the most contributing process was air transport. Using a specific approach to calculate GHG emissions of air transport always resulted in lower GHG emissions, especially upon a higher cargo capacity utilization. This illustrates the importance of including aircraft characteristics when calculating GHG emissions of cargo transport by air. It is even better when the average cargo capacity utilization is known, as an aircraft flying at a 100% cargo capacity utilization emits about one third less GHG emissions per kg product, compared to an aircraft flying at a 0.1% cargo capacity utilization. For potatoes from Peru, differences in GHG emissions due to selecting a specific process for a small cargo aircraft instead of using a generic number, were low.

The calculations above were based on mass allocation. Future research could include different approaches to allocation of GHG emissions between passengers and freight. Given that passenger aircrafts fly primarily to transport tourists, with freight as a side business (personal communication air cargo specialist in the Netherlands, January 27, 2022). This is especially relevant for tourist destinations, such as Aruba and other islands. An alternative approach to allocation could be based on allocating the GHG emissions of fuel used to fly the aircraft and passengers to the passengers, and to allocate the extra fuel use for an additional pallet to the freight.

3.4.2 GHG emissions of vegetable imports into Aruba

Fig. 3-4 shows an overview of GHG emissions of vegetable imports into Aruba, depicting the GHG emissions of passenger aircraft A330-303 at an 80% cargo capacity utilization. This plane was selected because the A330-303 was used most frequently in Aruba, and Davydenko et al. (2020) also assumed an 80% cargo capacity utilization. Fig. 3-4 includes GHG emissions from losses in two ways. First, 'postharvest losses' describe the GHG emissions of food losses emitted at the farm. Second, transportation and packaging of the losses are included in their respective life cycle stages. More details about the contribution of losses to overall GHG emissions are displayed in fig. 3-5.

Products imported by air had significantly higher GHG emissions (4.2 – 8.5 kg CO_2eq per kg) than products imported by sea (0.4 – 2.3 kg CO_2eq per kg). A high contribution from air transport for vegetable imports was also found by Frankowska et al. (2019) who conducted an LCA on imported vegetables to the United Kingdom. Sim et al. (2007) found that air transport contributed for 89% to

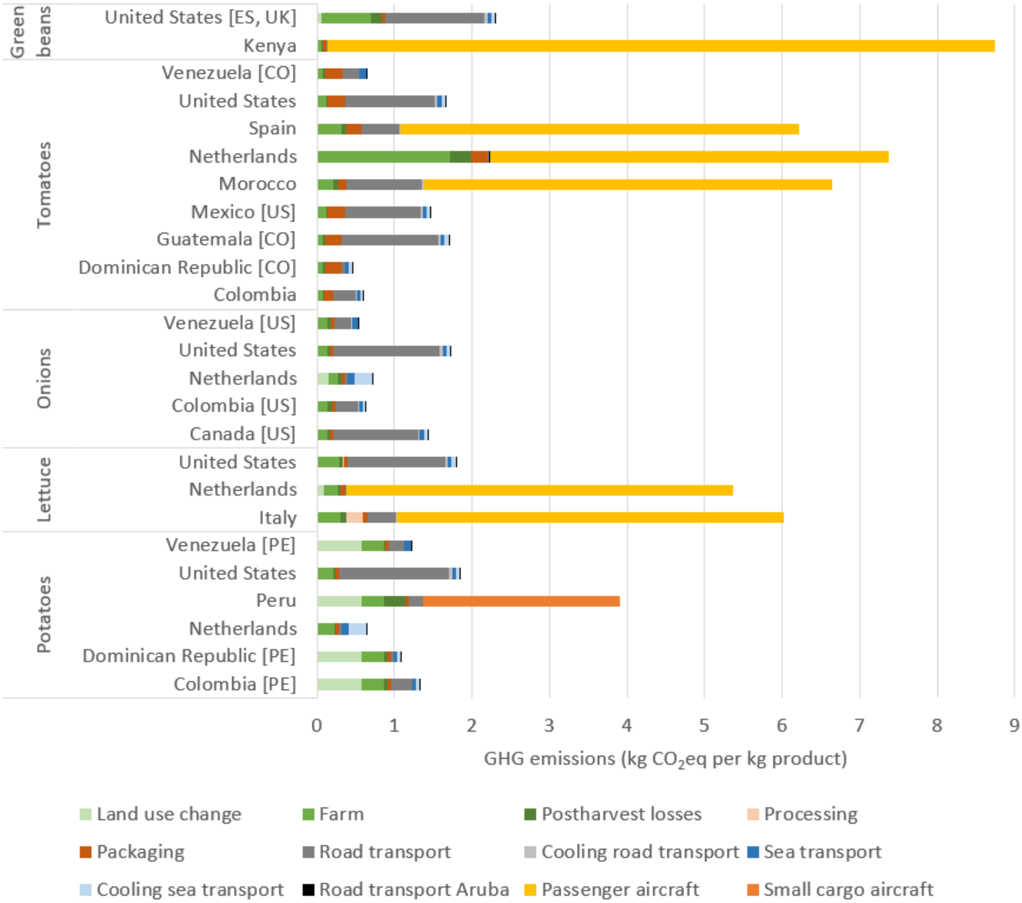

Figure 3-4 GHG emissions of products from different countries of origin imported into Aruba

GHG emissions of losses are included in the respective life cycle phases. The 2 letter codes represent the proxies used for the farm stage only: Colombia (CO), Spain (ES), Peru (PE), United Kingdom (UK), and the United States (US).

the carbon footprint of importing French beans from Kenya to England. In our study, the air transport of green beans from Kenya contributed for 99% to the total GHG emissions. The higher contribution of this study is related to the relatively long flight because green beans were first transported to the Netherlands, and then to Aruba. Michalský & Hooda (2015) found that when importing different fruits and vegetables to the United Kingdom, transport outside of the United

Kingdom contributed for 80% – 96% to total GHG emissions. This was mainly due to air transport.

For most products that were not flown in, the road transport contributed mostly to the GHG emissions. Except when there was only little road transport or when GHG emissions from agriculture were relatively high. For example, the amount of road transport was relatively low for the Netherlands (61 – 76 km) and the Dominican Republic (139 km), and relatively high for products from the United States, Canada, Guatemala, Mexico, and Morocco (2,800 – 4,700 km). GHG emissions of agriculture were particularly high for potatoes from Venezuela, Peru, the Dominican Republic, and Colombia. It should be kept in mind that for these potatoes, on-farm GHG emissions were based on a proxy of potatoes from Peru. For vegetables from these countries the fastest shipping route to Aruba was via Port Everglades in Miami, which resulted in a long road transport.

GHG emissions from packaging were highest for tomatoes. The reason is that tomato was the only vegetable in our selection that Poore & Nemecek (2018) categorized as delicate, while other vegetables were categorized as durable and therefore had less packaging with lower GHG emissions. However, not all products were always packaged, and for some products that were not observed in the supermarket but only via Trade Map, it is unknown whether they were packaged or not. Therefore, we advise that when comparing the GHG emissions of low-carbon products, such as sea-freighted vegetables, it is recommended to consider the packaging of the products. When making procurement decisions, one should also consider if the packaging protects the product and extends the product's shelf-life. For example, Shrivastava et al. (2022) have shown that the plastic wrapping of cucumbers reduced the carbon footprint of cucumber imports from Spain to Switzerland because it reduced food waste at retail by 4.8%.

The product with the highest differences in GHG emissions at the farm stage was tomatoes. GHG emissions at the farm for tomatoes from the Netherlands and Spain were about 22x and 4x higher compared to Colombia, respectively. The high GHG emissions of Dutch tomatoes were due to energy consumption of heated greenhouses. GHG emissions of Dutch tomatoes can fluctuate due to different production methods, but also due to fluctuating electricity sources (P. C. M.

Vermeulen & Van Der Lans, 2011). Verteramo Chiu et al. (2024) recently conducted a meta-analysis on LCA and LCI data of tomato and lettuce production and analysed studies published from 2000 – 2023. They found that GHG emissions were highest for tomatoes produced in greenhouses which were ventilated and/or heated, ranging from 0.13 to 10.10 kg CO_2eq per kg, with a mean of 2.00 kg CO_2eq per kg, from farm-to-regional retail. Whereas tomatoes produced on an open field or using plasticulture had mean GHG emissions of 0.68 and 0.40 kg CO_2eq per kg, respectively. For lettuce, the meta-analysis depicted a mean of 0.21, 0.22, 1.40, and 4.58 kg CO_2eq per kg, for open field production, plasticulture, greenhouses, and vertical farming, respectively (Verteramo Chiu et al., 2024). Other sources reported a range of 0.15 – 17.8 kg CO2eq per kg for lettuce, from cradle-to-RDC (Casey et al., 2022). Therefore, when making procurement choices, it is important to consider the production method of products produced in heated greenhouses.

The most GHG efficient country of origin differed per product. Considering the actual product-country of origin combinations, the following can be stated. For green beans, importing from the United States emitted least GHG emissions, as GHG emissions due to air transport were avoided. For tomatoes, importing from the Dominican Republic, Colombia, or Venezuela emitted least GHG emissions, due to the limited road transport, because mostly sea transport was used. However, if products would be sourced from farms relatively far away from the export ports, this would increase the GHG emissions. For onions, importing from the Netherlands, Venezuela, or Colombia emitted least GHG emissions, as a relatively long road transport step was avoided. For lettuce, importing from the United States emitted least GHG emissions, as GHG emissions due to air transport were avoided. For potatoes, importing from the Netherlands emitted least GHG emissions. However, when country-specific data on potatoes from the Dominican Republic and Colombia would be available, this may change the conclusion. In fig. 3-4, the contribution of losses was incorporated in the different life cycle stages. Fig. 3-5 shows the contribution of losses to total GHG emissions. The contribution of losses to total GHG emissions was lowest (3%) for potatoes from Venezuela, and highest for onions from Colombia (28%). There was not a single product or country of origin with most GHG emissions due to losses. Flown-in products had the highest contribution of GHG emissions due to losses, due to the transport of products that were lost during distribution. It should be kept in mind that we assumed that half of the losses during distribution occurred during air transport.

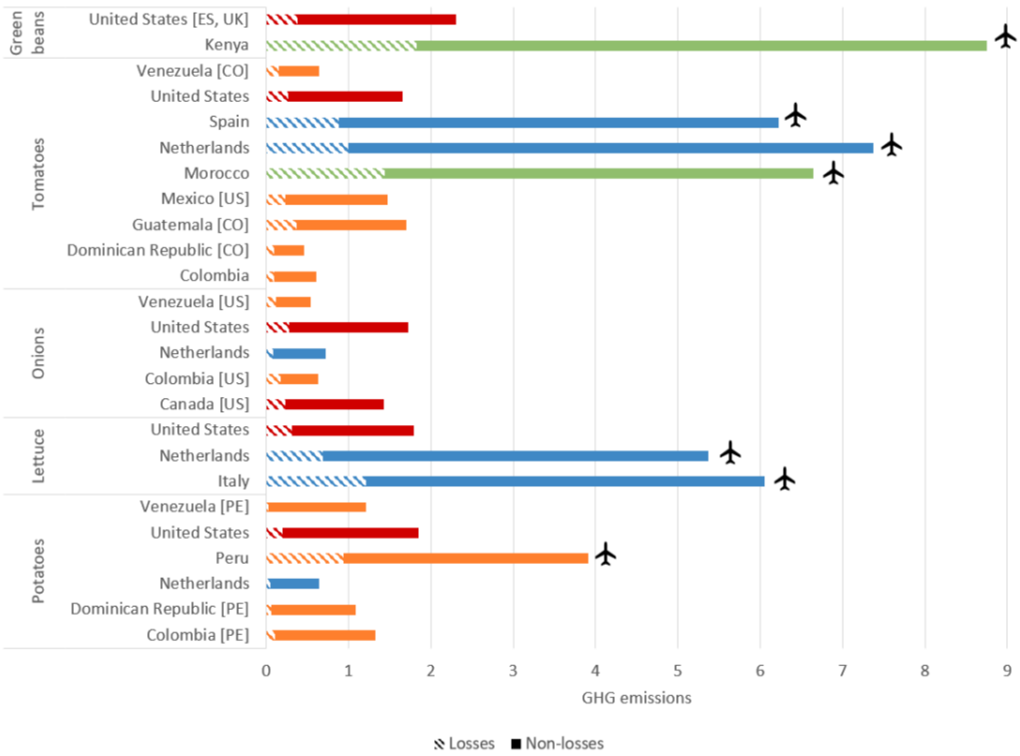

Figure 3-5 Contribution of losses to total GHG emissions of products

The symbols of a plane depict products imported by air. Each continent is represented by a colour: North America (red), Africa (green), Europe (blue), Latin America and the Caribbean (orange). The 2 letter codes represent the proxies used: Colombia (CO), Spain (ES), Peru (PE), United Kingdom (UK), and the United States (US).

Most GHG emissions due to losses occurred for green beans from Kenya and for tomatoes from Morocco. However, losses occurred during different life cycle stages. GHG emissions of losses for green beans from Kenya were nearly all due to air transport, whereas GHG emissions of losses for tomatoes from Morocco were mostly due to air transport, and partly due to road transport. Because, tomatoes from Morocco travelled a much greater distance by road (3,278 km) than green beans from Kenya (37 km).

Additional details about the contribution of different life cycle stages to GHG emissions of losses are shown in fig. S1 in the Online Supplementary Materials. These show that GHG emissions due to losses were mostly due to air transport or road transport, and due to postharvest losses in some cases.

Sea transport

Although sea transport was calculated with detailed information on maritime transport routes and ship characteristics, it usually was not one of the life cycle stages that contributed most to the overall GHG emissions. This was not the case for onions and potatoes from the Netherlands, which were shipped in chilled reefer containers for about one month. For these products, GHG emissions of maritime transport contributed to about half of the total GHG emissions, mostly due to cooling. GHG emissions of cooling were based on transit time. The average transit time from the Netherlands to Aruba was 30 days (www.cma-cgm.com), based on actual transport routes. Other sea distance calculators used by LCA practitioners (see introduction) estimated the average transit time at 18 days (www.sea-distances.org), 25 days (www.ports.com), or 46 days (www.searates.com). It should be kept in mind that maritime transport routes can change. To illustrate, for this research the average transit time was estimated at 30 days (January 2022), with one transit in France and one in Jamaica. Later (March 2024), the average transit time was 34 days as the route has changed and only one transit occurred in Colombia. Whereas container ships from the Netherlands used to take just 9 – 10 days in the past, this changed in 2020 (Superfood, personal communication, February 9, 2021).

Fig. 3-6 provides more insight into the build-up of the carbon footprint of maritime transport when using actual data on routes and container ships, for the route from the Netherlands to Aruba. The container ship sizes used for the first phase (the Netherlands to France), second phase (France to Jamaica), and third phase (Jamaica to Aruba) of the trip were 35,000 DWT, 50,000 DWT, and 15,000 DWT, respectively. GHG emissions (excl. cooling) of these ship sizes were 0.008 kg CO_2eq per tkm, 0.006 kg CO_2eq per tkm, and 0.025 kg CO_2eq per tkm. The smallest ship size did not only emit more GHG emissions per tonne of cargo due to its smaller size, but also because an 80% load factor and an empty return of the ship were assumed, due to Aruba's remoteness and limited exports. GHG emissions from Poore & Nemecek (2018) were 0.012 kg CO_2eq per tkm (excl. cooling). GHG emissions estimated with our more detailed method were 19% higher than using Poore & Nemecek (2018)'s method. This was mainly due to differences in GHG emissions from cooling, which were based on actual transit times (kg CO_2eq*day) in this article, whereas Poore & Nemecek (2018) based GHG emissions on distance sailed. Therefore, we recommend to LCA practitioners who need to calculate GHG emissions of relatively long sea transport, to consider using actual transit times, based on the schedule of an actual freight company.

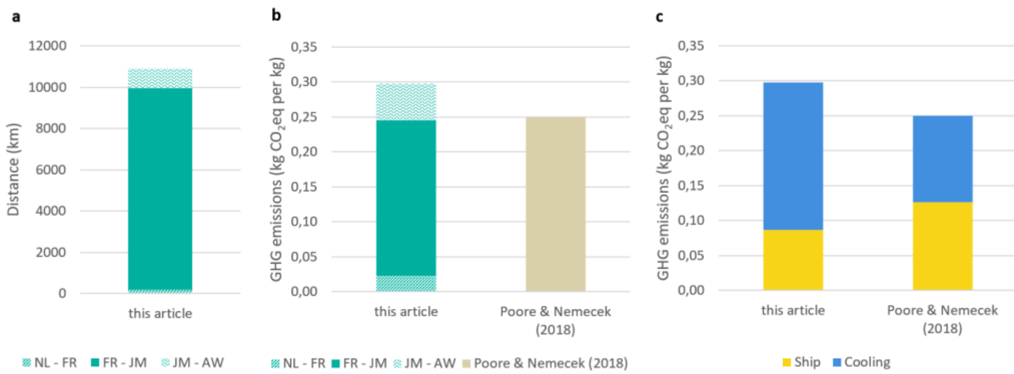

Figure 3-6 Distances per transshipment, GHG emissions, and contributions of sailing and cooling, to transport 1 kg product from the Netherlands to Aruba

a) Distances per transshipment: Netherlands to France (NL – FR), France to Jamaica (FR – JM), and Jamaica to Aruba (JM – AW).

b) GHG emissions of transport, per 1 kg product. Calculated using the methods of this article (left) and of Poore & Nemecek (2018) (right)

c) GHG emissions of sailing and cooling, per 1 kg product. Calculated using the methods of this article (left) and of Poore & Nemecek (2018) (right).

3.4.3 Low-GHG emissions vegetable imports into Aruba

For the vegetable imports in this study, there were two rules of thumb to lower the GHG emissions. First, source from origins that did not require air transport. Second, avoid products with relatively long road transport. In the case of Aruba these were products from North America that were grown relatively far from Miami, and products from Central America that were first trucked to port

Everglades in Miami. At this moment, the only countries in South America that exported directly to Aruba were Colombia and Venezuela. A suggestion for future research is to test these two rules of thumb for other case studies. When making procurement decisions, it would also be relevant to consider the degree of land use change, and the agricultural method for products produced in greenhouses, if this information is available.

3.5 CONCLUSION AND RECOMMENDATIONS

When identifying the product-country combinations of Aruba's vegetable imports, it was important to use trade data as well as to visit supermarkets. Vegetables that were imported to Aruba by sea rather than air had the lowest carbon footprint, due to the relatively high GHG emissions of air freight. The carbon footprint was even lower when significantly less road transport was required. Although GHG emissions of maritime transport were calculated in detail, these mostly still contributed little to overall GHG emissions. Although air freight was the most polluting transportation mode, our calculations showed that GHG emissions may have previously been overestimated by using generic data instead of data based on specific passenger aircrafts in use.

We suggest five recommendations to LCA practitioners: (1) For flown-in products, consider whether passenger or cargo aircrafts are being used in the case-study at hand. (2) GHG emissions of airfreight of perishable products may be underestimated when not including the weight of the 80 kg AKE container. Therefore, we recommend including the 80 kg AKE container or other container types in use. (3) We argue that when calculating the GHG emissions of air freighted imports it is important to consider which aircraft model was used. Additionally, it would be best to know the (average) freight and passenger utilization of the aircraft(s) (4). For more accurate GHG emissions of sea transport, we recommend using real transit times, as cooling contributed most to GHG emissions of sea transport. (5) If the goal of an LCA is to compare the GHG emissions of low-impact products, such as sea-freighted vegetables, it is advised to consider the amount of road transport and packaging types, as these formed hotspots in the GHG emissions for some products.

For consumers, we recommend following our two rules of thumb, since additional information on the production process is only rarely available in the supermarket or on the packaging. We recommend avoiding products that were known or suspected to be flown-in, and if possible, to avoid products that were suspected to have had a relatively long road transport. For Aruba, those are products from North America that were grown relatively far from Miami, and products from Central America that were first trucked to port Everglades in Miami. For importers who want to procure vegetables with a relatively low carbon footprint, we have three more recommendations next to our two rules of thumb described above: (1) For products produced in greenhouses, acquire information on the type of greenhouse used and the subsequent GHG emissions. (2) Acquire information about the likelihood of occurred land use change during production. (3) Acquire information about the packaging and if and how the packaging prevents losses.

Declaration of competing interests

The authors declare that there are no competing interests.

AI Statement

The authors have not used AI during the research or writing process.

Acknowledgements

The authors would like to thank the European Union for funding this research which is part of the SISSTEM project (FED/2019/406-549). The European Union was not involved in any parts of the research cycle. We acknowledge the Central Bureau of Statistics Aruba, and the supermarkets in Aruba for their data. We acknowledge our student Krista Farro from the Faculty of Arts and Science from the University of Aruba for data collection on vegetables in supermarkets. We acknowledge Jairo Jansen, Maintenance and Airworthiness Inspector at the Department of Civil Aviation Aruba (for 20+ years), for his help in calculating the GHG emissions of air transport in the belly of passenger planes. Finally, we would like to thank Freya Michiels, who during her time as post-doc at the Sustainability in the Agri-Food chain group at KU Leuven, advised on the first steps of this research.

PART III

RESEARCH ON FOOD AND BEVERAGES IN THE ABC ISLANDS

CHAPTER 4 CHARACTERISTICS OF RESEARCH ON HUMAN FOOD AND BEVERAGE PRODUCTION, SUPPLY, AND CONSUMPTION IN SMALL ISLANDS: A SCOPING REVIEW IN ARUBA, BONAIRE, AND CURACAO (DUTCH CARIBBEAN)

At the time of publishing this PhD thesis, the manuscript of this chapter was still under review. Supplementary Materials are available through this temporary link: https://my.hidrive.com/share/zdu9cvfwiw. Once this chapter is published in a peer-reviewed academic journal, the temporary link will be removed and Supplementary Materials will be available through the publisher only.

This chapter is based on: van Veghel, A. S., Perez, V. Sultan, S., & Pin, R.R. (2025). Characteristics of research on human food and beverage production, supply, and consumption in small islands: a scoping review in Aruba, Bonaire, and Curacao (Dutch Caribbean): [Manuscript in preparation]

CRediT authorship contribution statement

A.S. van Veghel: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization

4.1 ABSTRACT

This scoping review offers a first-time overview of publicly available research on human food and beverage production, supply, and consumption in Aruba, Bonaire, and Curacao (the ABC islands in the Dutch Caribbean). A protocol was developed based on JBI and PRISMA-ScR methods. Nine databases were searched: academic databases, local university and knowledge repositories, and global knowledge repositories. In total, 264 items were identified, of which 117 items were published from 2000 – March 2025. Characteristics were analysed for this latter group, to explore current relevant themes. The results indicated a diverse, accessible, and expanding research field, with notable growth over the past decade. This coincided with a period of growing global attention to food-related research, as well as expanded funding opportunities and international collaborations. Most items focused on Aruba, followed by Curacao and Bonaire. The supply chain stage most studied was agricultural production, with a focus on arable farming and fisheries.

Keywords: scoping review, food and beverages, Aruba, Bonaire, Curacao, Dutch Caribbean, small island

4.2 INTRODUCTION

Scoping reviews aim to provide an overview of or map the evidence from (diverse types of) literature, often to identify research gaps or to inform future research or policy, rather than to conduct in-depth analyses, as systematic reviews do (Peters et al., 2020). The number of scoping reviews has steadily increased since 2012 (Tricco et al., 2016) and many scoping reviews relating to food in small islands have been published in the past few years. A group of 57 small islands that face unique social, economic and environmental vulnerabilities are classified as Small Island Developing States (SIDS) by the United Nations (United Nations, 2026).

Examples of studies focusing on aspects of food systems in SIDS globally include the study of Brown et al. (2022) on interventions and policies aimed at improving nutrition, the study of Haynes et al. (2018) on health and other impacts of community food production, the study of Haynes et al. (2022) on interventions aimed at improving diets, and the study of Brugulat-Panés et al. (2025) on food sources and their interconnections in SIDS and other small islands.

Notably, almost none of these reviews included research about Aruba, Bonaire, and Curacao (the ABC islands in the Dutch Caribbean), except for Brugulat-Panés et al. (2025) who included one study about responses of Caribbean countries to the COVID-19 (coronavirus disease) pandemic (Beazley et al., 2020). The absence of studies about the ABC islands may be related to Aruba and Curacao's status as Associate Members in the United Nations list of SIDS (United Nations, 2026), resulting in their exclusion from some search queries (e.g., Brown et al., 2022). Besides, the scoping reviews above have specific inclusion criteria which may not match the food-related research executed in the ABC islands. For example, Brugulat-Panés et al. (2025) focused specifically on food sourcing, food acquisition, and food purchasing.

Other scoping reviews focused on specific regions, such as the Pacific Island Countries and Territories (PICTs). Georgeou et al. (2022) focused on food security and small holder farming, while Amato-Ali et al. (2025) focused on food losses. Fusi et al., (2025) studied food environments and concluded that there is a lack of research on the environmental surroundings that influence people's food choices. They defined several areas for future research: the promotion and pricing of different healthy and unhealthy foods and dietary patterns, food composition, retail food environments, cultural beliefs about food, policies and interventions to improve the food environment.

In the Caribbean region, scoping reviews have been conducted on various topics (e.g., Hassan et al., 2020; Iribarren et al., 2018; Zúñiga-Venegas et al., 2023) but only few reviews had a primary focus on food. Mohammadi et al. (2022) focused on food security challenges and improvement options and Hernández-Moreno et al. (2024) studied food security of older rural indigenous people. These reviews also did not include studies about the ABC islands.

4.2.1 Aruba, Bonaire, and Curacao

The ABC islands are part of the Dutch Kingdom and are situated north of Venezuela. Aruba and Curacao have a status of constituent countries, while

Bonaire is a special municipality of the Netherlands (Government of the Netherlands, 2025). Although most scoping reviews focusing on food system aspects of SIDS or of the Caribbean region did not include evidence from the ABC islands, it was observed that over the years a considerable amount of food-related research has been conducted about this region (e.g., Akkermans et al., 2024; de Jong et al., 2024; Mijts & Ballantyne, 2024). However, no overview consolidates and maps this body of work. An overview of existing research related to food can aid current and future researchers, policy makers, and those interested from the region and outside of the region, in understanding this research domain better.

Some characteristics and outcomes of the food systems of the ABC islands are their near import-dependence, high rates of overweight and obesity, and dependence on tourism (Alberts, 2020; D. Daal et al., 2021; International Monetary Fund. Western Hemisphere Dept., 2019; Mak et al., 2025; McElroy & Parry, 2010; Ministry of Tourism and Public Health et al., 2024; Schwiebbe et al., 2011; Verstraeten et al., 2017). The high tourism prevalence increases the required food supply. An increasing food import dependence is observed globally (Kummu et al., 2020; Porkka et al., 2013) and is a common characteristic of small islands as well (Brugulat-Panés et al., 2025; FAO, 2016). The ABC islands are nearly completely dependent on food imports (Boyer et al., 2020; Hira et al., 2023; Moreno Ramirez, 2024; Somers, 2012; van den Heuvel, 2017). However, policy makers and citizens have regularly expressed their interest and have initiated projects to increase local food production and consumption (e.g., Bon dia Aruba, 2023; Breukink, Eva, 2023; Szabó, 2025). High rates of overweight and obesity are partly caused by unhealthy eating habits. Results from national health surveys in Aruba and Curacao showed that over 84% of adults do not consume the recommended intake of fruits and/or vegetables (Ministry of Tourism and Public Health et al., 2024; Verstraeten et al., 2017). In Curacao, almost one third of adults drink soft drinks daily, and 41% of adults eat at fast food restaurants weekly (Verstraeten et al., 2017).

The examples above show an interest from different international and local parties in food production, supply, and consumption in the ABC islands. Other island researchers have also showed their interest in the food systems of the ABC islands (Giordana, 2024; Martin del Campo et al., 2023). Besides, recommendations from two World Bank reports on Aruba and Curacao's food security included the establishment of a National Food Security Knowledge Database, which should include the continuous identification of relevant research (Boyer et al., 2020 p. 54; Hira et al., 2023 p. 90). A scoping review can provide input for such databases.

To design the search strategy for this scoping review it is important to understand the local research environment. A recent mapping by Pin & van Heijningen (2025) showed characteristics of the academic community in the Dutch Caribbean, which comprises of six islands including the ABC islands. Their results revealed a highly geographically mobile and interconnected research community. About 55% of Dutch Caribbean researchers residing in the Netherlands have family roots and/or were born and/or were raised in the Dutch Caribbean. Most researchers and knowledge professionals have published in peer-reviewed journals or edited volumes (54% of all respondents), but many respondents (also) published their findings in reports (40% of all respondents). Interestingly, presenting research outcomes at academic conferences (55% of all respondents) occurred less frequently compared to presenting to local stakeholders or in community settings (59% of all respondents).

This implies that mapping existing research about the ABC islands requires a search strategy that reaches beyond academic peer-reviewed articles. Other scoping reviews focusing on islands found that almost half of the included evidence was drawn from grey literature (Brugulat-Panés et al., 2025; Georgeou et al., 2022; Mohammadi et al., 2022), "which provided valuable insights and rich contextual details, especially from documents involving local authors and contributors" (Brugulat-Panés et al., 2025).

4.2.2 Food system frameworks

To systematically map the results of the scoping review, a food system framework will be employed as a guiding analytical structure. Given the complexity of food systems, researchers have proposed different frameworks with varying focus points understand these systems (Dengerink & Brouwer, 2020). As this scoping review focuses on food and beverage (from now on: food) production, supply, and consumption, a framework that centralizes food system activities, or food supply chains, fits best. Relevant examples include those proposed by Ericksen (2008), UNEP (2016), HLPE (2017), van Berkum et al. (2018), and Woodhill et al. (2020).

The food systems framework of van Berkum et al. (2018) (Fig. 4-1) draws on the conceptual work of Ericksen (2008) and Ingram (2011). It aims to serve as an interdisciplinary conceptual framework for research and policy focused on sustainable solutions to ensure a sufficient supply of healthy food. Their food systems framework shows how environmental drivers (related to minerals, climate, water, biodiversity, fossil fuels, land, and soils) and socio-economic drivers (related to markets, policies, science & technology, social organisations, and individual factors) influence a number of food system activities. In turn, leading to food system outcomes that provide feedback loops to these environmental and socio-economic drivers (van Berkum et al., 2018). The framework provides an overview of the food system as well as the opportunity to zoom in on certain aspects of it.

For example, the part of the framework about food system outcomes distinguishes between three outcomes: socio-economic, food security, and environmental outcomes. When further zooming in on food security, one can distinguish food utilization, food stability, food access, food availability, food agency, and sustainability (FAO, 2021). One can then further zoom in on for example food utilization, which consists of nutritional value, social value, and food safety.

The food systems framework from van Berkum et al. (2018) will be used in this study, for three reasons. First, this framework allows to visually map research items on a generic as well as on a more detailed level. It uses one compact main framework (Fig. 4-1) with several sub-elements which provide more depth where needed. Given the proximity of island researchers to both the public and to policy makers, a concise and visually coherent model is preferred to facilitate effective communication. Second, this framework specifically mentioned food security, a topic frequently studied in the ABC islands (e.g., Akkermans et al., 2024; Bogaardt et al., 2015; Boyer et al., 2020; Brouwer et al., 2019; Hira et al., 2023; Sociaal Economische Raad, 2020; van den Dungen, 2025), also due to the COVID-19 pandemic (de Jong et al., 2024). Third, this framework was previously used in other reports related to food systems of Aruba and Bonaire (Akkermans et al., 2024; Smits, 2023).

4.2.3 Aim

The aim of this scoping review is to, for the first time, provide a comprehensive overview of published research on human food and beverage production, supply, and consumption in the ABC islands. This review seeks to strengthen knowledge on food in the ABC islands to assist researchers, policy makers, and other stakeholders –both within and outside the region– in understanding the characteristics of this research domain. Three main research questions are: 1) What was the volume of published research? 2) What were the characteristics of the published items? 3) Which topics were most frequently researched?

4.3 METHODS

To ensure a transparent, systematic process for conducting this scoping review, the objectives, inclusion criteria and methods were specified in advance and documented in a protocol (van Veghel et al., 2025). They were based on the JBI methodology (Peters et al., 2020, 2022) and on the PRISMA-ScR method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) (Tricco et al., 2018), both selected based on recommendations of the KU Leuven Libraries (KU Leuven, 2024).

The following sub-sections describe the scope and inclusion criteria, search strategy, the screening process for in- or excluding items, data extraction from included items, and adjustments to the food systems framework to map the topics researched.

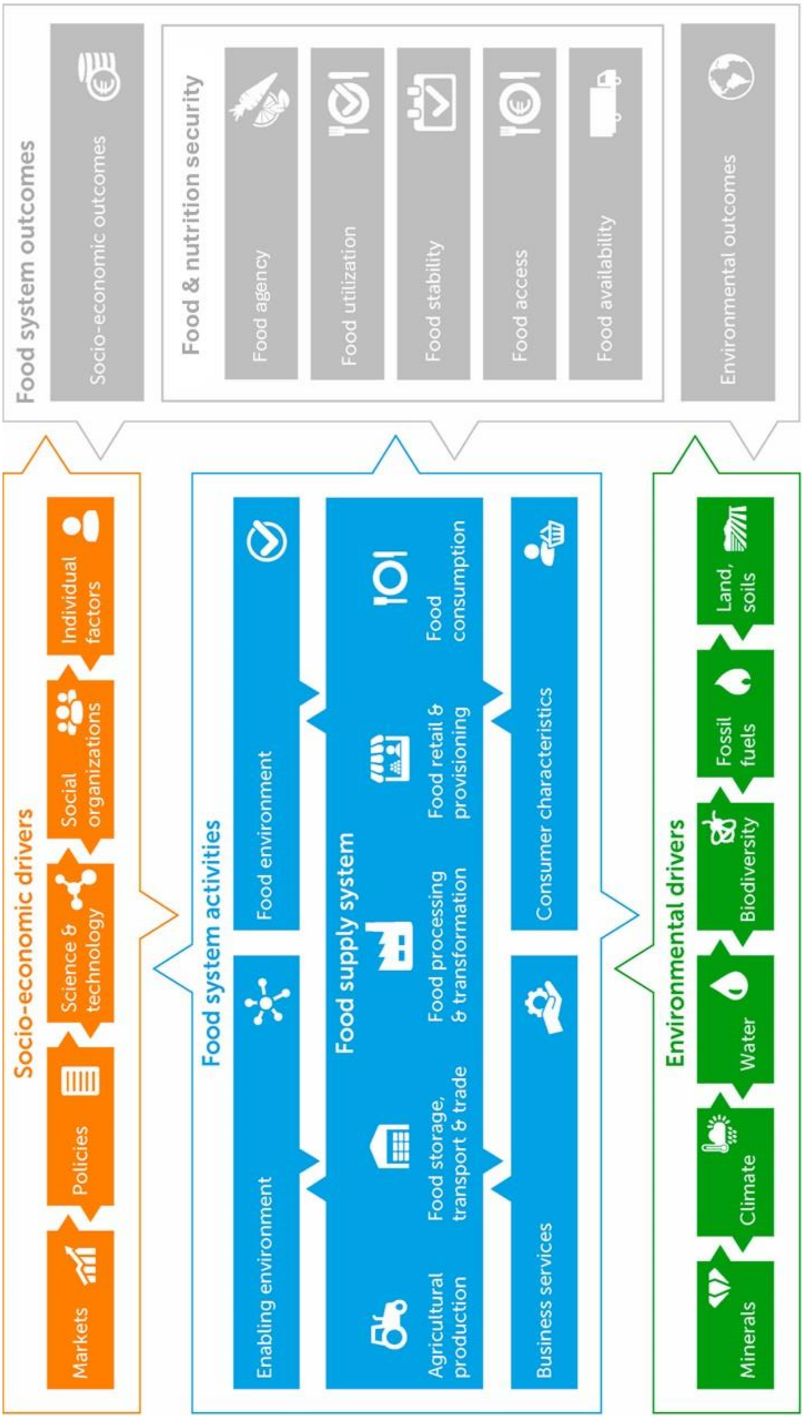

Figure 4-1 Food systems framework of van Berkum et al. (2018), adjusted from Borman et al. (2022)

4.3.1 Scope and inclusion criteria

The scope and inclusion criteria were defined using the PCC framework (JBI, 2015), as depicted in table 4-1. The review focused on published and publicly available research (concept) related to human food and beverage production, supply, and consumption (context), in the ABC islands (population). No contact was established with individuals or organizations to obtain non-public research, except for the Dutch Research Council (NWO), who organizes the annual Dutch Caribbean Research Week, where relevant contributions were expected. The primary focus was on research from the 21st century; however, to capture the broader evolution of the research landscape, no predefined time range was applied. Finally, publications in four languages were included: English, Dutch, Papiamento (spoken in Aruba), and Papiamentu (spoken in Bonaire and Curacao).

Table 4-1 PCC framework

Population	Aruba and/or Bonaire and/or Curacao.
Concept	Published and publicly available research, including academic articles and grey literature such as reports (e.g. policy reports, research reports), book chapters, conference proceedings, and theses. Excluded are documents which did not contain research, such as law descriptions, campaigns, newspaper articles, cookbooks, letters, patents, marketing research for specific brands, flyers, and non-scientific posters.
Context	Human food and beverage production (e.g., agriculture, processing), supply (e.g., distribution, availability) and consumption (e.g., dietary habits, food intake). Excluded are documents (1) indirectly related to these topics, for example documents on (marine) ecology or (fish) biology; (2) with breastmilk as a topic; (3) on clinically focused research; and (4) on water in general without specifying if this is for drinking or agricultural purposes.

4.3.2 Search strategy

A search strategy was developed, piloted across nine different databases, and was conducted from January 30 – April 3, 2025. A broad selection of databases were selected to include both academic and grey literature. The databases were divided into four categories: (1) global academic databases Web of Science and

Scopus; (2) local University repositories University of Aruba and University of Curacao (WorldCat and ABCD); (3) local knowledge repositories Coleccion Aruba and Dutch Caribbean Research Week (DCRW) archive; and (4) global knowledge repositories WorldCat and Google Scholar.

The local repositories can be described as follows. The University of Aruba repository, founded in 2024, serves as a source for regional (student) research. Two databases were available the University of Curacao (UoC), UoC on WorldCat and the ABCD Catalog. The ABCD Catalog contained items uploaded before 2016, after which the UoC transitioned to the UoC on WorldCat database. Coleccion Aruba, founded in 2022 (Bant et al., 2025), contained a wide range of documents (maps, images, videos, audio files, reports, and other documents) from twelve archives in the region, including Aruba, Bonaire, and Curacao. The DCRW is an annual Dutch Caribbean research conference, organized since 2021 by the Dutch Research Council (NWO). An overview of titles and abstracts from presentation and invited speakers was obtained for 2022 – 2024.

A search strategy was developed for each database. Search queries for Web of Science and Scopus were discussed with a KU Leuven librarian. Other search queries were based on those and were adjusted to fit the limitations of the databases. Detailed search strategies are shown in the Supplementary Materials. The search queries centralized the word “food”, different food types, and words related to agriculture and fisheries. It was kept broad because limited items about the ABC islands were included in other scoping reviews (Brugulat-Panés et al., 2025; Hernández-Moreno et al., 2024; Mohammadi et al., 2022).

Results were copied to Excel since most of the selected databases did not offer an option to export all retrieved items in a suitable format. Deduplication occurred manually based on the title, year, and document type. Duplicates were first removed between the databases of category 1 (Global academic databases), Web of Science and Scopus. Other duplicates were removed after all items were extracted.

4.3.3 Screening of retrieved items

The following steps were carried out by Amber van Veghel (author 1), Veronica Perez (author 2), and Renske Pin (author 3). First, two screening pilots were conducted on a sub-set of items from Web of Science and Scopus, using the criteria mentioned in table 4-1. It was determined beforehand that the authors would start screening after a minimum consensus rate of 75% was achieved, according to the guidelines of Peters et al. (2020).

Second, authors 1 and 2 screened all items and discussed any discrepancies afterwards. Table 4-2 depicts the screening approach per database. When possible, screening occurred at the level of title and keywords in the first round and at the level of the abstract in the second round. However, in most databases the abstract could not be hidden when viewing the title and was therefore immediately reviewed. Items without an abstract were screened either on introduction and conclusion, summary, table of contents, or on full text. For books with different research papers, each relevant paper was included as a separate item. If no abstract was available, the item was searched on Google and/or Google Scholar.

Third, some items from the UoC were not available online and had to be requested from the UoC library. Eventually, 53 physical documents were retrieved from the physical UoC repository. Fourth, after screening all items, a structured consistency check was performed by authors 1 and 3.

Table 4-2 Screening approach per database

Depending on the characteristics of each database, screening occurred in one or in two rounds. * When an abstract was not available, the item was screened either using the introduction and conclusion, the summary, the table of contents, or full text.

Source	**Round 1**			**Round 2**		
	Title	Keywords	Abstract*	Title	Keywords	Abstract*
Web of Science	x	x				x
Scopus	x	x				x
University of Aruba	x	x	x			
UoC WorldCat	x	x	x			
UoC ABCD	x	x				x
Coleccion	x	x	x			
DCRW	x					x
Google Scholar	x	x	x			
WorldCat	x	x	x			

4.3.4 Data extraction of included items

Data extraction and analysis were performed in Excel. Seventeen descriptive and five interpretative variables were extracted by author 1.

The following seventeen descriptive variables were extracted: (1) author names; (2) article title; (3) document type; (4) author keywords; (5) abstract or summary or introduction and conclusion or table of contents; (6) affiliations; (7) author country based on location of institute; (8) island(s) studied; (9) publication year; (10) DOI or URL; (11) open access status; and when applicable also the (12) journal title; (13) book title, or (14) conference title; (15) funding mechanism; (16) funding country or countries; (17) number of citations. Items published by the University of the Netherlands Antilles were labelled as the University of Curacao, due to the institution's name change in 2011. Items were considered open access only if they were immediately accessible without any barriers (Budapest Open Access Initiative, 2002). The number of citations were recorded for Web of Science, Scopus, and Google Scholar. For articles detected in multiple databases the number of citations sometimes varied, and the highest number was recorded.

Five interpretative variables were extracted: (1) food types; (2) food system aspects, based on the food systems framework of van Berkum et al. (2018); (3) supply chain stage (based on van Berkum et al. (2018)); (4) methods; and (5) specific methods. Methods were classified as quantitative, qualitative, or a combination of quantitative and qualitative methods. The specific methods were surveys, interviews, desk research or narrative essays, experiments, unknown, other methods, or mixed methods. Data extraction of the interpretative variables was tested by authors 1 and 2 on 10% of the sample size. Afterwards, all data was extracted by author 1.

Data extraction was performed primarily using the information source on which the item was screened. For example, if an item was screened on its abstract, only the abstract was used for determining the supply chain. However, for the methodology, the methods section was screened and the figures were scanned. In cases of missing author affiliations, LinkedIn was used as a supplementary source, to gain as much insight as possible on author's affiliations.

4.3.5 Food systems framework

As previously mentioned, the food systems framework of van Berkum et al. (2018) (Fig. 4-1) was used to assess the most studied food system aspects and supply chain stages. The framework was copied from Borman et al. (2022) and adjusted to include the six pillars of food and nutrition security mentioned by FAO et al. (2021). One of those pillars, sustainability, is not mentioned under *food security & nutrition*, as it was already included in the socio-economic and environmental outcomes. Definitions of each part of the food system framework are provided in the Supplementary Materials.

4.4 RESULTS

The results presented in this section answer the previously posed research questions:

- Section 4.4.1: What was the volume of published research?
- Sections 4.4.2 and 4.4.3: What were the characteristics of the published items?
- Sections 4.4.4 and 4.4.5: Which topics were most frequently researched?

4.4.1 Research volume

A total of 3,272 items were identified and 264 items were included (Fig. 4-2), of which more than half (147 items) were published in the 20th century. Most items from the 20th century were found in local University and global knowledge repositories. Local University repositories remained an important source for items from the 21st century, but local knowledge repositories and global academic databases became an equally important source compared to global knowledge repositories.

Fig. 4-3A shows the number of publications per ten-year period, starting from 1900. The first item was published in 1901. Between 1900 and 1949, ten items or less were published per year. The number of publications increased between 1950 and 1989, followed by a decline in publications until 2009. Since 2010, the number of publications increased again and most items were published in the past 15 years, especially since 2019.

Moving forward, this scoping review focuses on further analysis of the 117 items published in the 21st century (Fig. 4-3B). In the first decade, items were not published yearly, no items were published between 2002 – 2003, and 2008 – 2009. Since 2010, at least one item has been published yearly. Since 2019, the number of publications has increased, and more than seven items were published yearly. A peak of 21 items was observed in 2024, showing an increased interest in this research area.

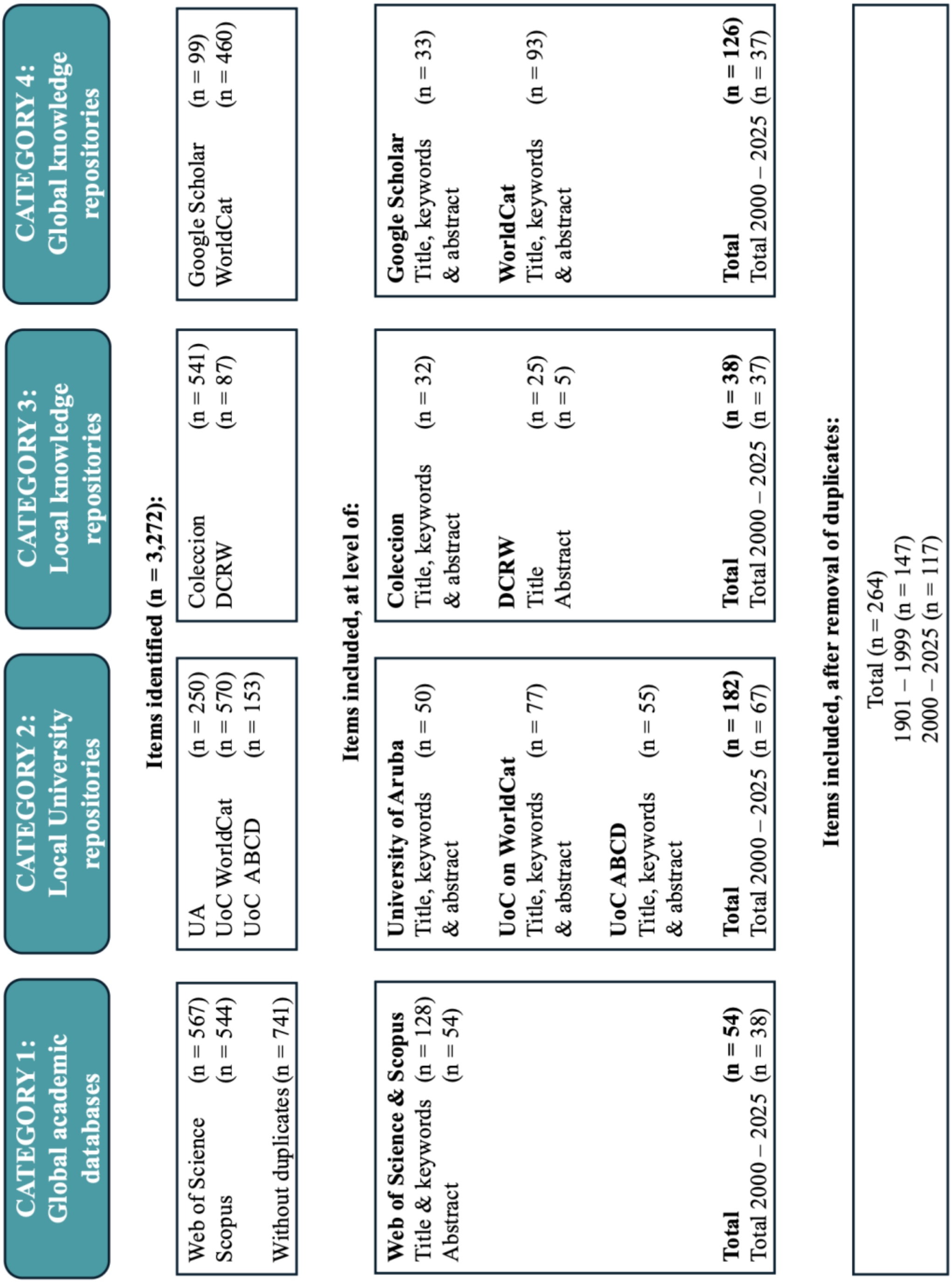

Figure 4-2 Number of retrieved and included items per database

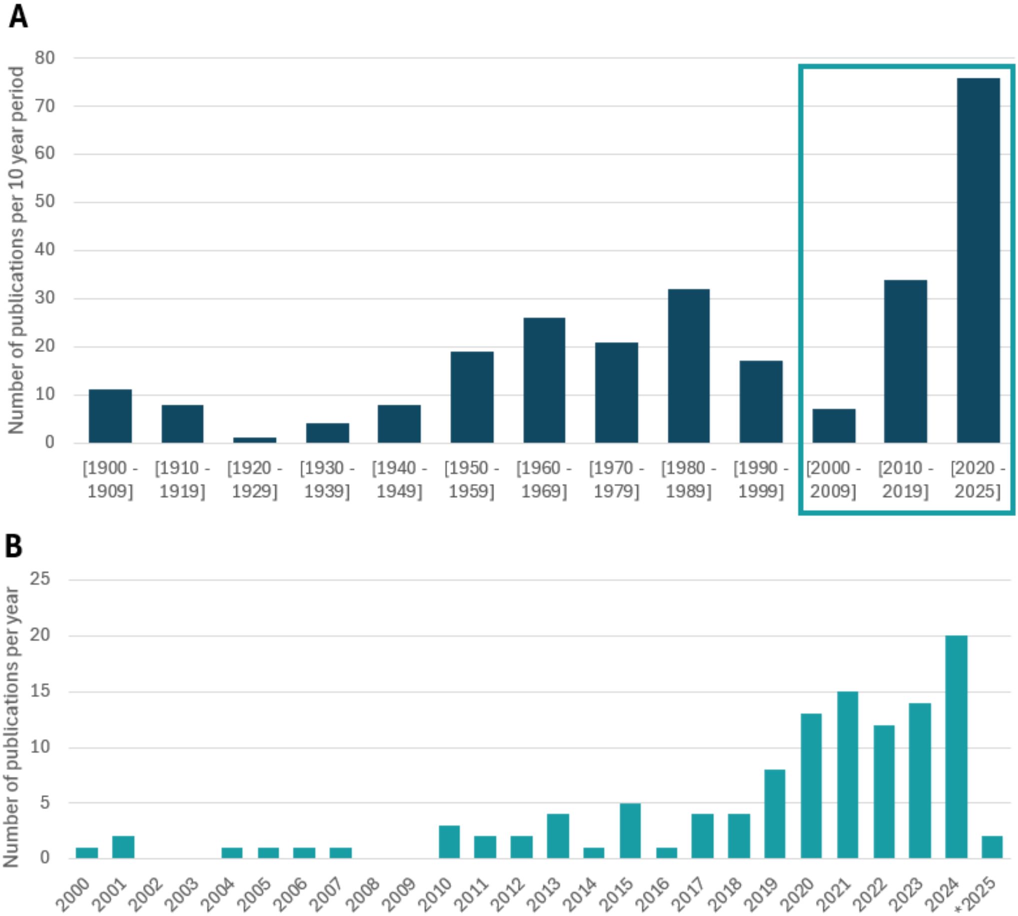

Figure 4-3 Number of publications per (A) 10-year period (1900 – March 2025) and (B) per year (2000 – March 2025)
*Results for 2025 were recorded until March.

4.4.2 Research characteristics

The research characteristics extracted from the sample (n = 117) included document types, open access status, funding mechanisms, and research methods.

Document types

Table 4-3 shows that the most common document types in the sample were authored by students (34%), followed by articles in peer-reviewed journals (26%).

The 30 articles were published in 29 different journals. Journal names can be viewed in the Supplementary Materials.

Table 4-3 Document types

Type	Count	Contribution to total
Article	30	26%
Thesis (Bachelor)	16	14%
Student paper	15	13%
Book chapter	12	10%
Report	11	9%
Presentation	11	9%
Thesis (Master)	6	5%
Conference Proceedings	5	4%
Brief / Factsheet	5	4%
Book	3	3%
Unknown	1	1%
Thesis (type unknown)	1	1%
Thesis (PhD)	1	1%
Total	117	100%

Open Access

Open access of research enhances broad dissemination and societal impact of research findings. Within the sample, 55% of the items were categorised as open access. Of the 53 items that were not open access, most were articles (13 items), bachelor thesis (12 items), presentations (11 items), or book chapters (8 items). Of the 30 journal articles, 17 were open access.

Funding mechanisms

Funding is an important driver of research activities. In this sample, over half of the items (55 items or 53% of the sample) acknowledged funding sources. The actual number of funded studies is likely higher, as some items (e.g., conference proceedings and presentations) were known to be funded but did not specify a funding mechanism. In such cases, consistent with the protocol, these items were classified as not funded.

Over two-thirds of the funded research was funded by a Dutch (21 items) or European (18 items) funding mechanism. Of the 21 items funded through Dutch funding mechanisms, ten received funding from the NWO and eight were financed by the Dutch government. Of the 18 items funded by European funding mechanisms, 15 were funded by the European Union and three were funded by the European Research Council. Almost all items funded by the European Union, with one exception, were published by the University of Aruba's SISSTEM project. Ten studies were funded or co-funded by one of the ABC islands. Other funding sources originated from the United States, France, Malaysia, Mexico, Canada, and global funds.

The earliest externally funded study in this area appeared in 2012 and was funded by the Netherlands. The Netherlands remained a steady funding country throughout the years. A peak (6 items) of research funded by the Netherlands was observed in 2024, which was all funded by the Dutch Research Council (NWO). In 2020, research funded by Europe was published for the first time. Europe was more frequently observed as a funder since 2022, mainly due to items published by the SISSTEM program at the University of Aruba.

Research methods

Most researchers used quantitative research methods (50 items or 43% of the sample), followed by qualitative research methods (28 items or 24% of the sample), and a combination of quantitative and qualitative research methods (26 items or 22% of the sample). The research method was unknown for the remaining items in the sample (13 items or 11% of the sample), which were either screened on title or were presentations for which research methods were not mentioned.

Most researchers used mixed methods (37 items or 31% of the sample), followed by experiments (27 items or 23% of the sample) and desk research (25 items or 21% of the sample). The most popular mixed method combinations were (1) desk research & interviews, (2) desk research, interviews & surveys, and (3) desk research & surveys.

4.4.3 Authorship characteristics

The authorship characteristics extracted from the sample (n = 117) included citations counts, characteristics of individual authors, and characteristics of institutions.

Citation counts

The number of citations by other researchers can be an indicator of the visibility of the research and its author(s). Citation counts were reported for 47% of the items in the sample and were only available for items retrieved from Web of Science, Scopus, or Google Scholar. The top 10 most cited items are depicted in table 4-4. The topics of the most cited articles were diverse and covered health related issues, algae production, fisheries, seawater desalination, promoting water consumption, and food safety.

Individual authors

To further measure an author's visibility, two indicators were used: publication frequency and frequency of first authorship. Frequency of citations was not used as an indicator as this was only available for less than half of the items. The number of individual authors identified was 226, of which 107 were first authors at least once. Table 4-5 shows the top 13 most productive authors, considering authors with more than two items in the sample. Authors with three items were only included if they were first author at least once. Most authors in the top 13 started publishing in the past five years. These authors were affiliated with 13 institutions, which were mostly located in the Dutch Caribbean (5 institutions) or in the Netherlands (4 institutions). Eight authors were affiliated with institutions in the Dutch Caribbean, most often with the University of Aruba (4 authors).

However, in the sample, most authors were incidental authors with one publication (178 or 79% of the sample). Other authors had two publications (31 authors or 14% of the sample), three publications (10 authors or 4% of the sample), or more than four publications (eight or 3% of the sample), with a mean of 1.4 items per author.

Table 4-4 Top 10 most cited articles

Abbreviations: Aruba (AW), Bonaire (BQ-BO), Curacao (CW). *The number of citations were retrieved through Scopus (S), Web of Science (WoS), and/or Google Scholar (GS).

Reference	Citations * (n)	Title	Island
(Katzman et al., 2004)	59 (S)	Not your "typical island woman": Anorexia nervosa is reported only in subcultures in Curaçao	CW
(Barten et al., 2020)	52 (S)	Bioprospecting and characterization of temperature tolerant microalgae from Bonaire	BQ-BO
(A. E. Johnson, 2010)	45 (WoS)	Reducing bycatch in coral reef trap fisheries: Escape gaps as a step towards sustainability	CW
(Kurihara et al., 2001)	43 (WoS + S)	Operation and reliability of very high-recovery seawater desalination technologies by brine conversion two-stage RO desalination system	CW
(Blakeway et al., 2019)	21 (GS)	Controlling lionfishes (Pterois spp.) with consumption: Survey data from Aruba demonstrate acceptance of non-native lionfishes on the menu and in seafood markets.	AW
(Franken et al., 2018)	21 (WoS + S)	Promoting water consumption on a Caribbean island: An intervention using children's social networks at schools	AW
(Hoogenboom et al., 2021)	19 (GS)	High levels of dioxins and PCBs in meat, fat and livers of free ranging pigs, goats, sheep and cows from the island of Curaçao	CW
(Ritger et al., 2018)	15 (S)	Bioaccumulation of mercury and other metal contaminants in invasive lionfish (Pterois volitans/miles) from Curaçao	CW
(Schwiebbe et al., 2011)	14 (WoS + S)	Childhood obesity in the Caribbean	BQ-BO
(Bonnélye et al., 2007)	13 (S)	Curacao, Netherlands Antilles: A successful example of boron removal on a seawater desalination plant	CW

Table 4-5 Top 13 most productive authors (>2 items in the sample)
Authors with three items were only included if they were the first author of at least one item. Authors were sorted on number of items in the sample, followed by items as first author, and alphabetical order of last names. Abbreviations: University of Aruba (UA), University of Curacao (UoC), Water- en energiebedrijf (WEB). * [number of items as first author].

Author	**Items in sample (n)***	**Affiliations**	**Document types (count)**	**Period**
van Veghel, Amber S.	8 [8]	(1) KU Leuven (2) UA	Article (2), Factsheet (1), Conf. proc. (2), presentation (2), report (1)	2021 – 2025
Mijts, Eric	7 [0]	UA	Article (2), Book chapter (3), Brief (1), Presentation (1)	2021 – 2024
de Kort, Rendell	5 [2]	(1) UA (2) World Bank	Book chapter (2), Policy brief (1), Report (2)	2020 – 2024
Peltzer, Karl	5 [2]	University of Limpopo	Book chapter (5)	2020
Pengpid, Supa	5 [2]	Mahidol University	Book chapter (5)	2020
Carmona Báez, Antonio	5 [1]	University of St. Martin	Book chapter (3), Brief (1), Presentation (1)	2021 – 2024
Echteld, Elisabeth	5 [0]	UoC	Book chapter (3), Brief (1), Presentation (1)	2021 – 2024
Geeraerd Ameryckx, Annemie	4 [0]	KU Leuven	Article (2), Conf. proc. (2)	2021 – 2024
Chin-On, Rocca C.	3 [3]	(1) Wageningen UR (2) WEB Bonaire	Article (2), Presentation (1)	2021 – 2024
Franken, Saskia C.M.	3 [3]	(1) Erasmus University Rotterdam (2) UA	Article (3)	2018 – 2025
Visser, Benjamin	3 [2]	(1) Samyama Permaculture Transition (2) UoC	Book chapter (2), Presentation (1)	2021 – 2024
Kist-van Holthe, Joana	3 [1]	VU Medical Center	Article (2)	2011 – 2018
van Beukering, Pieter P. J. H.	3 [1]	VU Amsterdam	Article (1), Brief (1), Report (1)	2012 – 2021

Authorship patterns revealed both international reach and local engagement. Considering all authors (not just first authors), most were affiliated with institutions in the Netherlands (95 authors) and/or the ABC islands (71 authors, of which 31 in Aruba, 23 in Curacao, 17 in Bonaire), and/or the United States (38 authors) and/or Belgium (20 authors). When considering only the 107 first authors, the majority were affiliated with institutions in the ABC islands (53 authors, of which 33 in Aruba, 13 in Curacao, and 7 in Bonaire) and/or the Netherlands (52 authors) and/or Belgium (21 authors) and/or the United States (11 authors). Dual affiliations were counted for both countries. Almost half of the first authors affiliated with an institution in the ABC islands were also affiliated with an institution in the Netherlands or Belgium.

Additional countries of affiliation included Australia, Barbados, Canada, France, Israel, Italy, Japan, South Africa, Spain, St. Maarten, the United Kingdom, and Venezuela. In total, author affiliations spanned 20 countries, highlighting a broad geographic interest in food-related topics in the ABC islands.

Institutions

The sample included items from 76 institutions. The ten institutions that published most items on food-related research in the ABC islands are depicted in table 4-6. The majority of the most productive institutions began publishing in this field in the past decade, except for the University of Curacao, which began publishing in 2000. Most items were published by the University of Aruba, followed by KU Leuven and Wageningen University & Research. The five most productive institutions contributed eleven or more items, 21 institutions contributed two to six items, and the remaining 50 institutions published once.

When considering all institutions and the countries in which they are established, most items in this review were published by institutions in the ABC islands (71 items, of which 40 in Aruba, 23 in Curacao, and 8 in Bonaire), followed by the Netherlands (57 items), the United States (26 items), and Belgium (15 items).

Table 4-6 The 10 most productive institutions

Institution	Country	Items in sample (n)	Period
University of Aruba	Aruba	37	2018 – 2025
KU Leuven	Belgium	15	2020 – 2025
Wageningen UR	Netherlands	14	2017 – 2024
University of Curacao	Curacao	11	2000 – 2024
Utrecht University	Netherlands	11	2017 – 2024
Unknown	Unknown	6	2006 – 2023
Mahidol University	Thailand	5	2020
TU Delft	Netherlands	5	2019 – 2023
University of Limpopo	South Africa	5	2020
University of St. Martin	St. Maarten	5	2021 – 2024

4.4.4 Research topics

The items in the sample (n = 117) were mapped according to islands studied, author keywords, food types, supply chain stages, and element(s) of the food systems framework studied.

Islands studied

Most items (106 items or 91% of the sample) focused on one of the ABC islands: mostly on Aruba (60 items), followed by Curacao (40 items) and Bonaire (31 items). The islands were rarely studied in parallel. Two items focused on all six islands in the Dutch Caribbean; these were published in 2001 and in 2024. Other items focusing on more than one of the ABC islands, were first published in 2017.

Author keywords

Most items in the sample did not report author keywords (74 items or 63% of the sample), including 30 out of 40 theses and student papers, and nine out of 11 reports. Author keywords were never provided for presentations and books. Of the 43 items that did report keywords, 202 diverse author keywords were identified (Fig. 4-4) Most keywords were used once (179 keywords or 89% of all keywords). The most frequently used keywords were: Caribbean (7 items), Aruba (7 items), Bonaire (5 items), Curaçao (5 items), and food security (4 items).

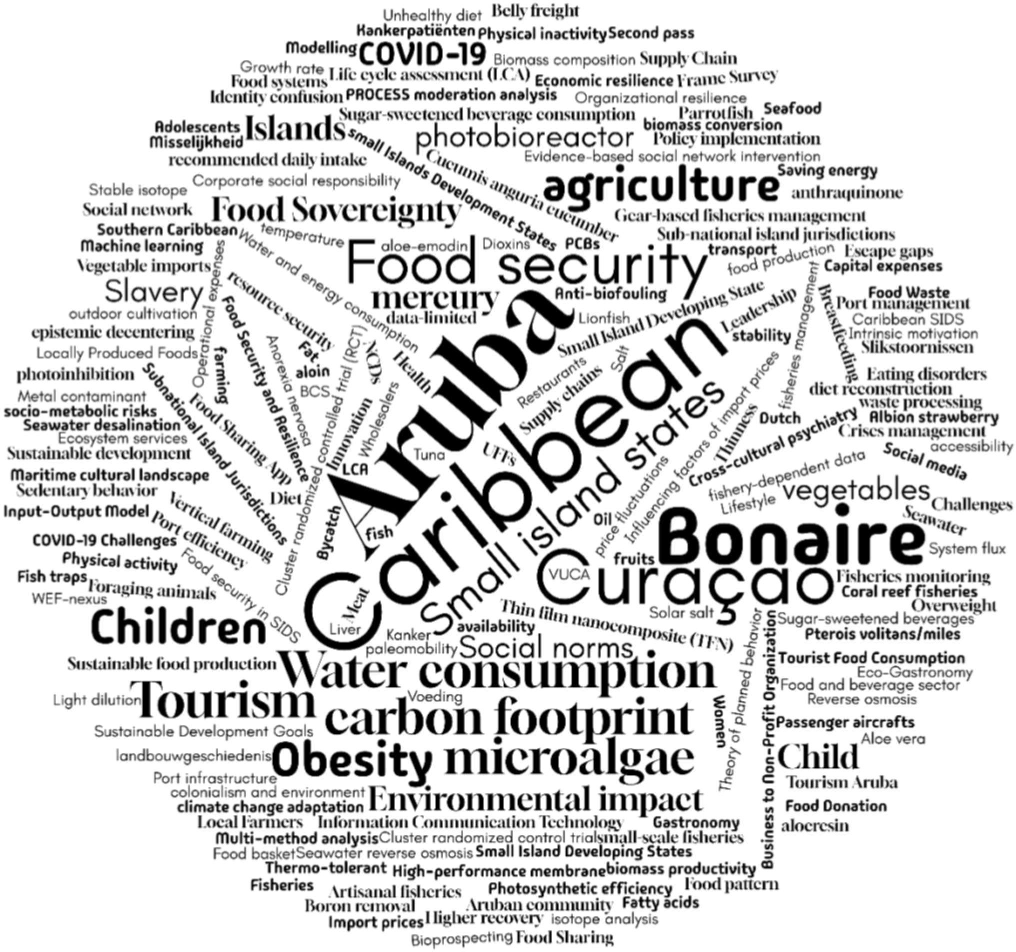

Figure 4-4 Word cloud with 202 author keywords, based on 43 items
Letter size reflects the observed frequency. Tool used: wordclouds.com.

Food types

The food types studied were identified per item. Half of the items focused on food in general. The other half focused on one or multiple food types. Fig. 4-5 shows that the most frequently studied food types were fish and seafood (25 items), vegetables (13 items), fruits (13 items), and beverages (12 items). Research on fish and seafood primarily focused on fisheries, although a few items also considered consumption. Most of these studies did not concentrate on a specific species, however, some focused on conch, lionfish, shrimp, or tuna.

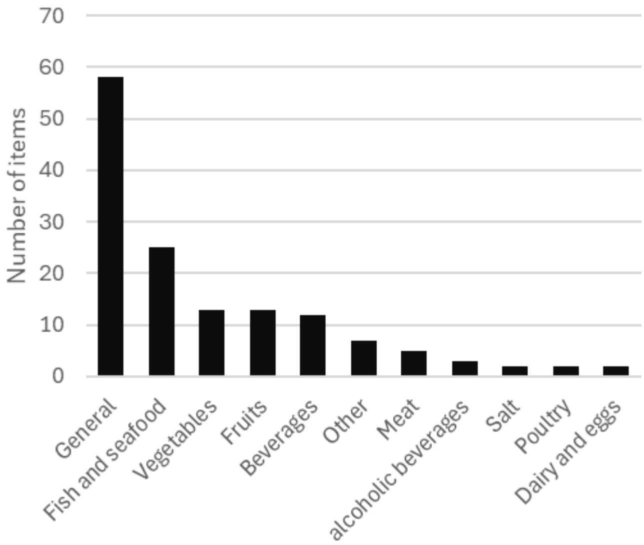

Figure 4-5 Food types studied (sample size: n = 117)

Supply chain stages

Supply chain stages were mapped using the food systems framework of van Berkum et al. (2018). Most items focused on a single supply chain stage (106 items or 91% of the sample). Fig. 4-6 shows that the most studied supply chain stage was "Agricultural production" (65 items or 56% of the sample), with a focus on "arable farming and horticulture" and "fisheries". Less frequently studied supply chain stages were "Food retail & provisioning" and "food consumption".

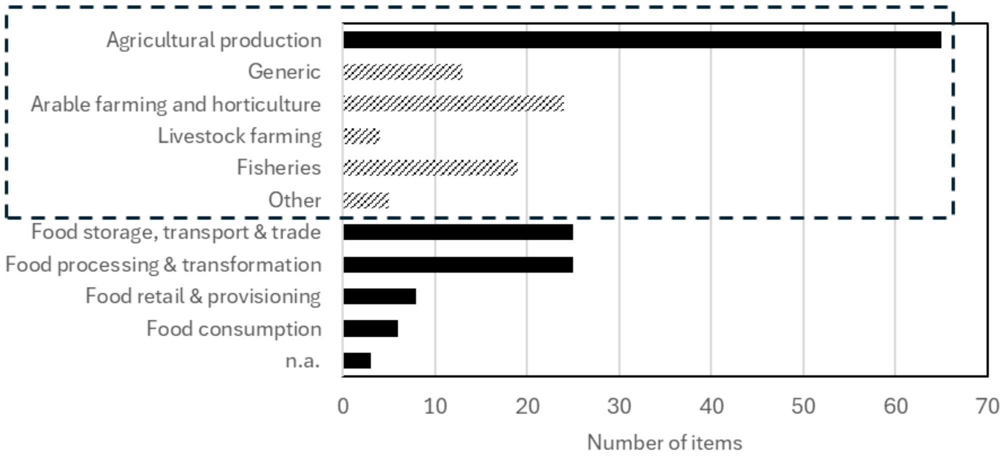

Figure 4-6 Supply chain stages studied (sample size: n = 117)
Some items covered multiple supply chain stages. Bars with a pattern fill indicate the types of agriculture contributing to *Agricultural production*.

4.4.5 Elements of the food systems framework studied

Each item was mapped against the food systems framework of van Berkum et al. (2018) (Fig. 4-1). Fig. 4-7 shows which elements (e.g., food system activities) and sub-elements (e.g., food supply system) from the framework were mostly studied; items were allowed to be mapped across multiple elements and sub-elements. When insufficient details were available, an item was not matched to a sub-element. Therefore, the total number of items per element may be different from the sum of items per sub-element. An overview of how each item was mapped is available in the Excel file (Supplementary Materials), including their abstracts, and URLs (when available).

Most publications considered food system activities and socio-economic drivers. In the following paragraphs, the topics studied are described per element of the food systems framework. References of studies will be provided without being complete.

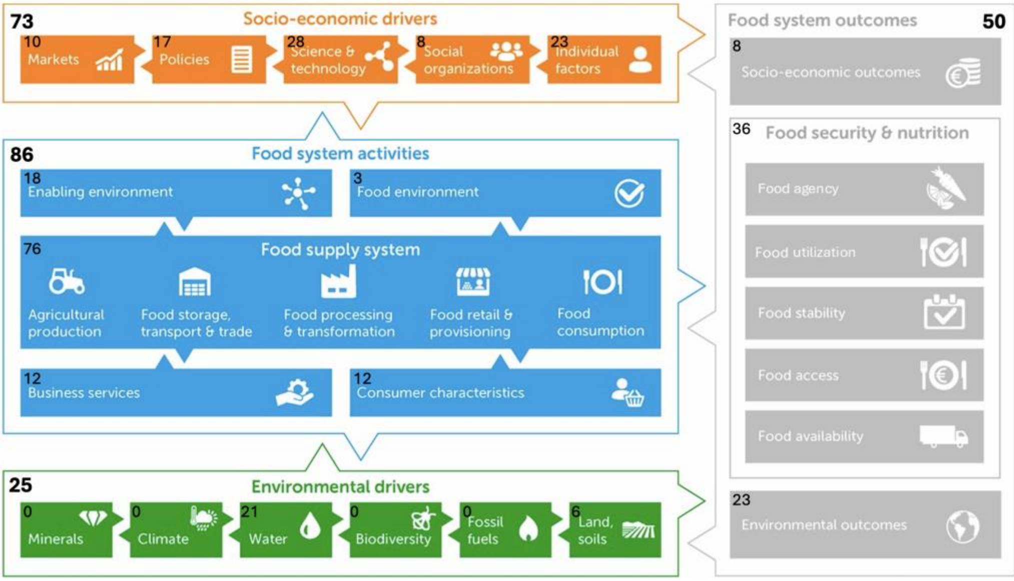

Figure 4-7 Number of items retrieved per element and sub-element of the food systems framework of van Berkum et al. (2018)
The total number of items per element may be different from the sum of items per sub-element because (1) if insufficient details were available, an item was not matched to a sub-element; and (2) one item may be matched to multiple sub-elements.

Food system activities

For the element "food system activities" (86 items), the most studied sub-element was the "food and beverage supply system" (76 items or 88% of 86 items). This sub-element covered a broad range of topics, encompassing all stages of the supply chain, from agricultural production to consumption. Most items mapped to this sub-element considered *agricultural production*, *food retail & provisioning*, and/or *food consumption* (words shown in italics are sub-sub-elements of the food systems framework).

Items on *agricultural production* considered crops, livestock, fisheries, salt production, novel production methods, history, food security, and sustainability issues. Items on novel production methods focused on the possibility of seawater agriculture and vertical farming in Aruba (Croes, 2016; Facun, 2021), microalgae production in Bonaire (Barten et al., 2020; Chin-On, 2021; Chin-On et al., 2022), and the feasibility of shrimp farming and the production of a circular pork production system in Curacao (Broeze et al., 2020; da Costa Figueira, 2005). Other studies focused on the implementation of agricultural techniques, such as community urban agriculture in Bonaire (van de Velde, 2022, 2023), and food forests in Curacao (Pruijs, 2022; Visser, 2021).

Items on *food retail & provisioning* focused on food supply (often related to food security or environmental outcomes), as well as the relation between food and tourism. In Aruba, studies were performed on the influence of food on the tourist's travel experience (Koolman, 2015), the perception on authentic Aruban restaurants by first-time and repeat tourists (DiPietro et al., 2019), organizational resilience within the food and beverage sector during the COVID-19 pandemic (Oosterwolde, 2021), and the possible role of an urban food sharing app to decrease food waste from hotels, restaurants, and supermarkets (Nieuw, 2021). In Curacao, Willems (2015) studied the preference of consumers for franchise or local restaurants.

Items on *food consumption* covered pre-colonial food consumption, modern food consumption, as well as the willingness to adjust current food consumption. Two studies assessed dietary habits of Indigenous individuals, in prehistoric Aruba (Mickleburgh & Laffoon, 2018), and in pre-colonial Bonaire (Seferidou et al., 2023). Blakeway et al. (2019) studied the willingness of consumers in Aruba to consume lionfish. Franken et al. (2023) compared behavioural determinants of water consumption between Aruban and Dutch adolescents. Studies were also conducted on promoting water consumption among children through a social network intervention in Aruba (Franken et al., 2018, 2025). Other health-related studies focused on dietary behaviours (including alcohol use), overweight, obesity, and diabetes (Arias & de Droog, 2021; Grêaux et al., 2013; Peltzer & Pengpid, 2020; Pengpid & Peltzer, 2020a, 2020b; Verstraeten et al., 2020).

Socio-economic drivers

For the element "socio-economic drivers" (73 items), the most studied sub-elements were "science & technology" (28 items or 38% of 73 items), "individual factors" (23 items or 32% of 73 items), and "policies" (17 items or 23% of 73 items).

Items on “science & technology” mostly considered *farm inputs* and/or *food processing and technology*. Items on *farm inputs* considered innovations such as utilizing aloe vera waste to produce animal and aquaculture feeds (Semerel et al., 2023) or using fish aggregating devices to increase catches (Vermeij et al., 2019). Also, opportunities for rainwater harvesting were explored (Coelman, 2024; J. Johnson, 2024). In Aruba, farmers were interviewed about the use of pesticides, fertilizers, and water resources (Bekhoven et al., 2023). Items on *food processing and technology* mostly considered seawater desalination in Aruba (Croes, 2016), Bonaire (Atkinson, 2020), or Curacao (Bonnélye et al., 2007; Curiel, 2000; Kim-Hak et al., 2015). One study considered drying characteristics of Aruban mangoes (Obispo, 2024).

Items on *individual factors* related to lifestyle, attitudes, beliefs, values, and culture. Studies related to the fishing culture were conducted on all three islands (Kraan, 2017; Mac Donald, 2019; Mehlhart, 2020). In Bonaire, Stelten & Antczak (2023) studied the lives of people who lived and worked at the salt pans between 1921 and 1960. In Curacao, a book on 500 years of agricultural history was published by Daal (2021), who also discussed the influence of the Dutch colony on the development of agriculture.

Items on *policies* included research directly related to policies as well as research on the role of the government in food related issues. For example, de Jong et al. (2024) analysed 13 studies related to the effect of the COVID-19 pandemic on the food systems of Aruba, Curacao, and St. Maarten. “government” was among the themes that emerged most frequently in relation to strengthening food systems. In Aruba, Blom (2024) studied how a goat restriction policy in the national park can affect commercialisation and market participation of goat farmers; van der Loo, (2022b) studied how food sovereignty can be protected in public policy and developed as a notion in international human rights law; Rincon-Bravo (2021) analysed hindering and stimulating factors of effective policy implementation to target non-communicable diseases risk factors, including unhealthy diets; two authors assessed political gaps and political factors influencing rainwater harvesting (Diaz-Maroto Knöfler, 2024; Ramos Monzón, 2024). In Bonaire, Johnson (2024) presented about the development of a sustainability rainwater management plan. In Curacao, Pruijs (2022) reviewed policy documents related to food, to explore the role of agroecology in achieving food sovereignty.

Food system outcomes

For the element "food system outcomes" (50 items), the most studied sub-elements were "food & nutrition security" (36 items or 72% of 50 items) and "environmental outcomes" (23 items or 46% of 50 items). The sum exceeds 100% as items could be mapped against more than one sub-element. Items on "food & nutrition security" mostly considered *food availability*, *food utilisation*, and/or *food stability*.

Food security was assessed on a national level for all three islands (Bogaardt et al., 2015; Boyer et al., 2020; Carmona Baez et al., 2021; de Kort et al., 2024; Hira et al., 2023; Visser et al., 2024). Others focused on a specific food group, such as fisheries (Boekhoudt & Hadicurari, 2015; Mac Donald, 2019; Vermeij et al., 2019), or on factors influencing costs of fruit and vegetable imports in Aruba (Habibe, 2019). For *food utilisation*, the most common aspect studied was food safety, which was analysed in fish (metal accumulation), livestock (dioxins and PCBs), pork (a safe food waste collection system) and water from desalination (boron) (Bonnélye et al., 2007; Broeze et al., 2020; Davidson et al., 2013; Hoogenboom et al., 2021; Ritger et al., 2018). Interestingly, all items on *food stability* were published after 2020, as a response to the COVID-19 pandemic.

Items on "environmental outcomes" were often related to environmental impact or carbon footprint calculations, on a national level, as well as for case studies on chicken, seafood, and vegetable imports (Bleukx et al., 2021; Couwet et al., 2022; De Vlieghere, 2022; De Vlieghere et al., 2023; Lelièvre-Damit, 2022; van Veghel, 2021, 2022, 2024; van Veghel et al., 2021, 2022, 2024). Another focus was on marine resources, such as reducing by-catch in coral reef trap fisheries (Johnson, 2010), linking ecosystem services (such as fisheries) to the sustainable development goals (Palacios et al., 2021), declining fish stocks (Mac Donald, 2019; Vermeij et al., 2019), and the role of fishermen in marine conservation projects (Mehlhart, 2020).

Environmental drivers

The element "environmental drivers" was least studied. Most items in this element related to "water", either focusing on rainwater harvesting, on desalination, or on the role of water in the water-energy-food (WEF) nexus. For example, Jurgens (2020) performed a spatial analysis on urbanization patterns and land use change in five Caribbean islands, among which Aruba, Bonaire, and Curacao. In Bonaire, Oliemans (2019) applied systems and transition management theory to a WEF nexus approach and proposed three pathways to reach an integrated transition water, energy, and food systems. Van der Geest & Slijkerman (2019) added 'ecosystems' and 'nutrition security' to this approach.

4.5 DISCUSSION

4.5.1 Contextualization of the results

This scoping review provides a comprehensive overview of research on human food and beverage production, supply, and consumption in the ABC islands. A search in nine databases resulted in the identification of 264 relevant items of which 117 were published in the past 25 years (2000 – March 2025). Characteristics were analysed for this latter group, to explore current relevant themes. An increase in publications was observed since 2019, with a peak in 2024. Most items focused on Aruba, followed by Curacao and Bonaire, with a focus on agricultural production, specifically arable farming (e.g., fruits, vegetables) and fisheries. Authors were mostly affiliated with institutions within the Dutch Kingdom.

Research volume

The increased number of publications since 2019 coincides with a period of growing global attention for food-related research in small islands (Amato-Ali et al., 2025; Brugulat-Panés et al., 2025; Fusi et al., 2025), as well as expanded funding opportunities (outside of the ABC islands) and international collaborations. Funding and author characteristics were analysed for the subset from 2000 – March 2025. The first item funded through external funding was observed in 2012, with funding from the Netherlands. In 2020, the first item funded by the European Union was observed. In the past five years, the majority of the most productive authors started publishing. In the past decade, the majority of the top 10 most productive institutions in this review began publishing in this field, except for the University of Curacao, which began publishing in 2000 on this topic. Besides, at the time of publication, new research outputs in this field had already been observed, including nine student papers (Mijts & Ballantyne, 2025).

Authorship

Authorship was analysed at the country, institutional, and individual levels. At the country level, most items originated from institutions in the ABC islands, followed by the Netherlands. Institutionally, the University of Aruba published the most items, followed by KU Leuven and Wageningen University & Research. At the author level, most authors were affiliated with institutions in the Netherlands, while most first authors were affiliated with institutions in the ABC islands; nearly half of the latter also held affiliations in the Netherlands or Belgium.

This seems in line with affiliation patterns of the broader Dutch Caribbean research community, of which 47% is based in the ABC islands and 40% in the Netherlands (Pin & van Heijningen, 2025). Also, it is not uncommon for island-based academics to have an affiliation with a university in e.g. Europe or the Caribbean region to gain access to resources such as funding, libraries, or PhD supervisors.

Research topics

The sample included a diverse coverage of food related topics and aspects of the food system studied. Some observations were made about the content of the sample, while a full analysis was out of scope. In the past decade, certain topics were observed in the sample for the first time. Since 2019, a few authors studied the water-energy-food nexus framework in an island context, and interventions and action research emerged across several food system elements. Since 2020, items on food stability were first observed. Since 2022, the term food sovereignty was first coined.

4.5.2 Limitations

Six limitations of this study were identified.

Underestimated volume of 20th century items. The number of items from the 20th century may have been underestimated, for two reasons. First, two additional databases with many 20th century publications were discovered during the search: (1) the bibliography of the Netherlands Antilles (Criens, 1985), which contained titles in Dutch and English of a selection of studies on agriculture, livestock, and fisheries; and (2) the New West Indian Guide, which is a Caribbean journal that contained items from 1919 to 2025 (JSTOR, 2025). Second, the search strategy was not adjusted according to 20th century word use. For example, the old Dutch word for fisheries is spelled as "visscherij" instead of the modern word "visserij".

Double publications. Some items were published more than once in different formats. For example, as part of a collection of student papers, and in the form of a bachelor dissertation. Although this shows the research activity, it may provide a bias in the research subjects studied.

Information availability for mapping of food systems framework. According to the protocol, research topics were mapped based on the level at which they were included. Which was usually at the level of title, abstract, or introduction and conclusion. Some items had more extensive abstracts than others and were therefore mapped against more elements of the food systems framework, causing a potential bias in food system elements studied.

No quality assessment. An assessment of study quality was not conducted, meaning it is possible that some of the included studies have methodological flaws that may affect the reliability of the findings. This may especially occur for research carried out by students, which constituted about one third of the sample. However, a lack of quality assessment is a common limitation of scoping reviews (e.g., Brugulat-Panés et al., 2025).

Completeness. Although a comprehensive search strategy across nine diverse databases, including local repositories, was executed, the authors do not claim that all existing items were retrieved, for two reasons. First, after conducting the search strategy, two additional databases came to the attention of the authors: the online library of the Dutch Caribbean Agriculture, Livestock, and Fisheries Alliance (DCALFA) (https://dcalfa.com/online-library/) and the Dutch Caribbean Biodiversity Database (DCBD) (https://www.dcbd.nl/), both contained a report on the seafood supply chain of the Bonaire (WWF-Netherlands & Good Fish Foundation, 2020). Second, some reports published on websites of local institutions came to the attention of the authors, and these websites were not searched. For example, a study from the Directie Volksgezondheid (English: Directorate-General for Public Health) which included dietary behaviour in 2023 in Aruba could not be retrieved through the databases searched in this study (Ministry of Tourism and Public Health et al., 2024).

Reproducibility of the affiliation data. Missing author affiliations were identified through LinkedIN sources, which may limit the reproducibility of the affiliation data.

4.5.3 Recommendations

Researchers in the ABC islands. Most items (82 items or 69% of the sample) were retrieved through only one of nine databases. Each database contained at least one unique item. Therefore, using multiple databases when searching food-related literature from the ABC islands is recommended. Most items that were only available in one database were found in the University of Aruba repository (34 items), Web of Science and/or Scopus (20 items), or WorldCat (11 items).

Future repetitions. To retrieve more items in future repetitions of this scoping review it is recommended to also search websites of local institutes and to add the DCALFA and DCBD online libraries to the search strategy. Additional steps could include screening reference lists and/or citations.

Researchers in small islands. As mentioned in the introduction, other scoping review related to food in small islands never or limitedly included articles from the ABC islands. This scoping review showed that most items were retrieved from local University repositories. When searching research about small islands, it is therefore recommended to include local (University) repositories in the search strategy.

Researchers in small islands. Similar to the limited visibility of research about food in the ABC islands, this may exist for other small islands as well. Due to the large number of small islands, visibility of items in databases may increase when the region (e.g., Caribbean, Pacific) and a reference to the small island context are mentioned in the title and/or keywords and/or abstract.

4.6 CONCLUSION

This scoping review aimed to provide a first-time comprehensive overview of existing research on human food and beverage production, supply, and consumption in the ABC islands (Aruba, Bonaire, Curacao). Research characteristics of the past 25 years (2000 – March 2025) were analysed to explore current relevant themes. Nine databases were searched: academic databases, local university repositories, local knowledge repositories, and global knowledge repositories. Based on predefined inclusion criteria, 117 publications from the past 25 years were included in this review. They were categorized, based on indicators derived from abstracts and reference information, such as research and author characteristics but also the supply chain stages and aspects of the food system studied, based on the framework of van Berkum et al. (2018).

The results indicated a diverse, accessible, and expanding research field, with notable growth over the past decade. This coincided with a period of growing global attention to food-related research, as well as expanded funding opportunities and international collaborations. The supply chain stage most studied was agricultural production, with a focus on arable farming (e.g., fruits, vegetables) and fisheries. Authorship patterns revealed a diverse, local and international research community, a strong Dutch Kingdom and European orientation in collaboration and funding. Although most authors had affiliations with Dutch institutions, most first authors had affiliations with institutions in the ABC islands. The University of Aruba published most items within the sample. Also, most research was about Aruba and the ABC islands were rarely studied in parallel. The number of individual authors identified was 226, of which 107 were first authors at least once. Most were incidental authors (79% of authors and 66% of institutions) and a mean of 1.4 items per author were published.

This comprehensive overview contributed to increased transparency on recent research on food production, supply, and consumption in the ABC islands and can be used by researchers, policy makers, and those interested from the region and outside of the region, to understand this research domain better.

Acknowledgements
This research was part of Amber van Veghel's PhD trajectory within the SISSTEM project at KU Leuven and the University of Aruba. The SISSTEM project was funded by the European Union (FED/2019/406-549). We thank Chayenne van Meel from KU Leuven Libraries for assisting in drafting the search strategy. We thank Dr. Eric Mijts from the University of Aruba for his feedback during the conceptualization phase of this project. We thank Irwin Korstjens and colleagues from the University of Curacao Library for their support and effort in assisting us.

PART IV

GENERAL DISCUSSION & CONCLUSION

CHAPTER 5 GENERAL DISCUSSION AND CONCLUSION

The main research question of this doctoral study was: *"What is the environmental impact of an island's food imports, and how can its food system be studied through diverse analytical approaches?"*

This research question was explored through three Research Objectives (RO):

1. To quantify the environmental impact of food transport to Aruba
2. To quantify the environmental impact of food import choices for Aruba
3. To examine the characteristics of research on food production, supply, and consumption in Aruba, Bonaire, and Curacao

In this chapter, the findings of each RO are explored, followed by reflections on academic contributions, future perspectives, suggestions for future research, and the conclusion.

5.1 RO 1 – ENVIRONMENTAL IMPACT OF FOOD TRANSPORT TO ARUBA

The aim of RO 1 was to quantify the environmental impact of sea and air transport of food imports to Aruba, while considering small island characteristics of the supply chains. For sea transport, actual maritime transport routes were modelled for canned tuna and vegetable imports, considering vessel sizes, load factors, possible empty return, and actual transport distances and durations. For air transport, GHG emissions of air freighting vegetable imports were calculated based on characteristics of passenger aircrafts attending Aruba.

5.1.1 Sea freight

Despite differences in characteristics of maritime transport routes for small islands and a detailed modelling approach, sea transport generally did not contribute much to total GHG emissions of food imports to islands, in line with global research (e.g., Roibás et al., 2018; Thévenot et al., 2013; Ziegler et al., 2021). Except for products with relatively low GHG emissions, as shown in table 5-1 on the contribution of sea freight to total GHG emissions of products. Differences between products were related to the total GHG emissions of the product, sailing distances, and transit times. To illustrate, for products with relatively high GHG emissions, such as 11.5 kg CO_2eq per kg canned tuna, GHG emissions from sea freight did not contribute much to total GHG emissions, even not upon relatively long sailing distances and transit times. While about half of the GHG emissions of potato and onion imports from the Netherlands were caused by maritime transport. Thus, we recommend to only adjust the methodology of sea transport for products with a relatively low carbon footprint, relatively long transit time, or for feed imports of locally produced meat. Otherwise, it may be more worthwhile to focus resources on modelling other supply chain aspects.

For longer transport times, such as from the Netherlands to Aruba (~ 4 weeks, via Jamaica), GHG emissions estimated with our detailed method were 19% higher per trip than when using average data, due to the cooling required. Therefore, when calculating GHG emissions of longer sea transport routes, such as one month, it is recommended to separately model cooling of the products, based on actual transit times.

Table 5-1 Contribution of sea freight to total GHG emissions of food imports by sea
Based on data on canned tuna from chapter 2 (De Vlieghere et al., 2023) and a selection of vegetables from chapter 3 (van Veghel et al., 2024). Abbreviations: the Netherlands (NL), the United States (US)
* The contribution of sea freight GHG emissions to total GHG emissions
** Sea freight refers to feed imports from Europe and Argentina to Reúnion Island

Product	Total GHG emissions (kg CO_2eq / kg)	Sea freight GHG emissions (kg CO_2eq / kg)	Sailing distance (km)	Transit time (days)	Reference
Tuna (small can, vegetable oil)	11.5	0.4 (3%)*	20,271	37	(De Vlieghere et al., 2023)
Potatoes (NL)	0.6	0.3 (50%)	10,901	30	(van Veghel et al., 2024)
Onions (NL)	0.7	0.3 (43%)	10,901	30	(van Veghel et al., 2024)
Onions (US)	1.7	0.1 (6%)	2,330	6	(van Veghel et al., 2024)
Local poultry production	2.5	0.2 (9%)**	> 10,000	n.a.	(Thévenot et al., 2013)

5.1.2 Air freight

In chapter 3, GHG emissions of vegetable imports to Aruba were calculated, including several airfreighted vegetables. GHG emissions of air transport always contributed most to GHG emissions of air freighted vegetables. However, when characteristics of specific passenger aircrafts attending Aruba were used, GHG emissions were lower than when using generic models. Generic models are used by most LCA practitioners. Also, it was found that the 80 kg AKE container used to refrigerate vegetables on board, increased GHG emissions of air transport and should therefore be considered in life cycle inventories. Besides, when more of the cargo capacity was utilized, this resulted in lower GHG emissions per kg product. Finally, it is recommended to LCA practitioners to model GHG emissions of air transport using specific aircraft characteristics. This could be more challenging for larger countries however where more different aircraft types may be used and data may be more difficult to obtain. In our case, it was very easy to obtain data on the use of passenger aircrafts, given the proximity of the author to employees at the airport, because of living on a small island.

5.2 RO 2 – ENVIRONMENTAL IMPACT OF FOOD IMPORT CHOICES FOR ARUBA

In chapter 2, the environmental impact and environmental hotspots of different types of canned tuna imports were identified. Differences between the focus products related to the brand (supply chain and accompanying liquid) and the can size (small or large). Although differences in environmental impact existed, these were generally small and the results did not indicate a preferred canned tuna option due to limited data availability on the fuel use for tuna catches of different brands. The study did confirm that large cans are preferred over small cans, provided that all tuna is consumed.

In chapter 3, two rules of thumb were formulated to import vegetables with lower GHG emissions: to avoid products with long road transport distances and to avoid air freighted products. Vegetables imported by air had significantly higher GHG emissions (4.2–8.3 kg CO_2eq per kg) than products imported by sea (0.4–2.3 kg CO_2eq per kg). Products imported by sea with a long road transport were products from North America that were grown relatively far from port Everglades in Miami (US export port to Aruba), and products from Central America that were first trucked to port Everglades in Miami. For example, tomatoes from Mexico or Guatemala.

Although air transport had the highest GHG emissions, section 5.2.1 explores the pros and cons of avoiding are freighted foods. Section 5.2.2 explores limitations and opportunities in applying LCA to quantify the environmental impact of food imports. Section 5.2.3 explores future research in GHG emissions of recipes and national food supply.

5.2.1 Should islanders avoid flown-in foods?

Given the relatively high contribution (70% - 99%) of air transport to the carbon footprint of air freighted vegetable imports (Frankowska et al., 2019; Michalský &

Hooda, 2015; Sim et al., 2007; van Veghel et al., 2024), one could argue that these foods should be avoided to decrease GHG emissions. However, one could argue that islanders should not avoid all flown-in foods, for two reasons.

First, for food security reasons it is preferable to have multiple food import partner countries (Hira et al., 2023). Especially given the relationship of the Dutch Caribbean islands with the Netherlands. If a major supply chain disruption causes other trade partners to (temporarily) not export fresh food to the Dutch Caribbean islands, a relatively high carbon footprint of flown-in fresh foods should not be a reason to stop importing fresh foods from the Netherlands.

Second, the main purpose of aircrafts is transportation of tourists and there is usually cargo space left on passenger aircrafts flying from Amsterdam to Aruba. Also, increasing the amount of cargo on a plane lowers the GHG emissions per kg cargo. However, it is recommended to avoid “double flown-in foods”, such as green beans imported from Kenya to the Netherlands. These foods have relatively high GHG emissions, and alternatives with lower GHG emissions are available.

5.2.2 Limitations and opportunities in applying LCA to quantify the environmental impact of food imports

Limitations to quantifying the environmental impact of canned tuna and vegetable imports were a lack of data availability and a lack of transparency. A lack of *transparency* was observed in the study on canned tuna when selecting target products, as some brands supplied more supply chain information than others. The environmental impact could not be calculated for canned tuna from brands with limited supply chain transparency. A lack of *data availability* was observed in the study on canned tuna imports by the lack of data on fuel use efficiency in different regions, and in the study on vegetable imports by the lack of data for specific product-country combinations. Such geographic limitations are common in the field of food and LCA (Bohnes et al., 2019; Bohnes & Laurent, 2021; Clark et al., 2022; Halpern et al., 2019; Ruiz-Salmón et al., 2021), and should be considered when drafting future research proposals.

For future research proposals on the environmental impact of foods in Aruba or other countries, four aspects should be considered. First, limited LCAs are performed on lower-value and/or less widely produced foods such as honey, animal fats, and specific grains such as millet and sorghum (Clark et al., 2022; Halpern et al., 2019). Second, for some products, such as seafood, there is a lack of available data and a lack of transparency in methods and life cycle inventories (Bohnes et al., 2019; Bohnes & Laurent, 2021; Ruiz-Salmón et al., 2021). Third, although an increase in LCA studies of agri-products in Latin America has been observed in the past ten years (Ramírez-Cando et al., 2025), most LCA studies on food have focused on Europe, North America, Oceania, Brazil, and China (Clune et al., 2017; Jolliet, 2022; Marrero et al., 2022; Notarnicola, Sala, et al., 2017; Poore & Nemecek, 2018; Ruiz-Salmón et al., 2021). This implies a higher chance of having to utilize proxies when focusing on food imports from Latin America and the Caribbean (LAC region). Fourth, if research is carried out in collaboration with or commissioned by the hospitality sector, this may increase data availability and applicability of the results.

While limited data is available for some products in the LAC region, more data is available for other products. Globally, frequently studied foods include dairy, beef, chicken, rice, maize, wheat, and pork (Halpern et al., 2019; Jolliet, 2022), while Halpern et al. (2019) also specifically mentioned tomatoes. A recent study examined GHG emissions of Brazilian beef exports and included data on beef exports to Aruba, including GHG emissions of region-specific land use change (i.e., deforestation) (Lathuillière et al., 2025). Utilizing this data to help consumers make food choices with lower GHG emissions could be further explored, especially as beef is one of the products with highest GHG emissions (see figure 1-4) and has a high contribution to total GHG emissions of diets and national food consumption (Babiker et al., 2022; Goossens & Schmidt, 2025; WWF, 2020). Eventually, future research on the environmental impact of foods in the ABC islands should focus on societal impact as well as data availability.

LCA methods

As explained in the introduction (section 1.2.2), a variation in methods used makes it more difficult to compare results of different LCA studies (Clune et al., 2017; Goossens & Schmidt, 2025). Within this doctoral dissertation, two different

IPCC methods were used to measure GHG emissions. This should have been avoided and it is challenging to know how the results may change upon using updated IPCC methods. A case study on the environmental impact of barley production in Spain showed that the application of the IPCC 2019 guidelines versus the IPCC 2006 guidelines increased GHG emissions by a factor 1.12 in wet regions and by a factor 0.86 in dry regions (Hierro et al., 2021). Thus, illustrating the importance of using updated environmental impact methods.

5.2.3 GHG emissions of recipes and national food supply

In future research, LCA applications to foods in the ABC islands could focus on GHG emissions of recipes, local diets, or national food supply, Comparing GHG emissions of recipes may aid consumers in making more conscious choices. To illustrate, a beef lasagne may emit over six or twenty-two times more GHG emissions compared to a vegetarian or a vegan lasagne, respectively (Takacs et al., 2022). Often, diets with lower GHG emissions are also healthier, tackling other challenges such as a high obesity prevalence, which was also observed in the ABC islands (Arias & de Droog, 2021; Schwiebbe et al., 2011; Verstraeten et al., 2017).

Quantifying GHG emissions of the national food supply of the ABC islands is particularly interesting because it could fill a research gap. Numerous studies focused on the environmental impact of national or global food consumption (Goossens & Schmidt, 2025; Perignon & Darmon, 2021) and some global studies also included Caribbean islands[1] (Chaudhary & Krishna, 2019; Loken et al., 2020; Lucas et al., 2021; Springmann et al., 2018). However, Dutch Caribbean islands were never included (Goossens & Schmidt, 2025), as they did not supply food supply and consumption data to the FAO (FAO, 2025).

Data on GHG emissions of the national food supply is especially relevant because food systems are associated with almost a third of global anthropogenic GHG

[1] Antigua and Barbuda, Cuba, Dominican Republic, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, and Barbados

emissions (Babiker et al., 2022; Rockström et al., 2025; S. J. Vermeulen et al., 2012) and their mitigation potential is recognized by the IPCC (Babiker et al., 2022). Insight into the contribution of different food types to total GHG emissions of an island's food supply can aid in decision-making on lowering GHG emissions of the national food supply. A challenge which may arise when conducting such research in the future is the distinction between food consumption of tourists and citizens. The ongoing Total Diet Study from the Department of Public Health in Aruba will deliver data on food consumption of citizens using dietary recalls (Gobierno Aruba, 2025), this data may be used to distinguish between food consumption of locals and tourists. It is not known to the author if such studies are planned in Bonaire or Curacao.

It is likely that GHG emissions of Aruba's food supply are above the global average of 5.8 kg CO_2eq per capita per day, as GHG emissions of food consumption in Latin America and the Caribbean were 13.5 kg CO_2eq per capita per day (Loken et al., 2020). Preliminary research by KU Leuven bachelor students on Aruba and Curacao's food imports showed GHG emissions of 11.8 and 15.4 kg CO_2eq per capita per day, respectively (Bleukx et al., 2021; Couwet et al., 2022). These results could be over- or underestimated compared to the global average GHG emissions per capita per day. Because, the results from Aruba and Curacao were based on the food supply, which includes food waste and food consumed by tourists and undocumented citizens, while global results were based on food consumption. Also, global results were based on regionalized data while the results from Aruba and Curacao were based on global average. Using regionalized data is especially important for products with a high variability and high impact, such as beef (Loken et al., 2020). Beef imports contributed for 29% and 27% to GHG emissions of Aruba and Curacao's food imports, while their contribution to total food imports was about 3 weight % (Bleukx et al., 2021; Couwet et al., 2022).

Furthermore, it should be considered that these studies were not peer-reviewed, did not include local production, and did not consider the variability in GHG emissions of foods, and therefore require a more detailed modelling approach. Also, the effect of dietary switches (e.g., Shah et al., 2024) on GHG emissions was not examined but may aid consumers to make more sustainable food choices.

Meanwhile, both small islands and international institutions are concerned about insufficient global mitigation efforts and demand accelerated action (IPCC, 2023; United Nations, 2024, 2024; United Nations Environment Programme, 2024). “Aruba’s national goals mention lowering CO_2 emissions with a minimum of 45% between 2010 and 2030 (excl. effects from the refinery) and aims towards being CO_2 neutral in 2050, in accordance with the Paris agreement” (Kabinet van de Gevolmachtigde Minister van Aruba, n.d.). To achieve this, the focus is on increasing renewable energy and reducing the dependence on fossil fuels (Kabinet van de Gevolmachtigde Minister van Aruba, n.d.; Ministry of Economic Affairs, Communication and Sustainable Development, 2023).

The lack of including GHG emissions of food into national climate change mitigation plans is a globally recognized issue (WWF & Climate Focus, n.d.). However, the importance of reducing GHG emissions of food systems is widely recognized. To illustrate, Rockström et al. (2025) stated that “no safe solution to climate and biodiversity crises is possible without a global food systems transformation. Even if a global energy transition away from fossil fuels occurs, food systems will cause the world to breach the Paris Climate agreement of limiting global mean surface temperature to 1.5°C”.

Although food systems were not mentioned in national climate change mitigation ambitions, there is a local interest in this topic. The author was invited at the Energy & Climate Conference in 2025 in Curacao inform the attendees about the role of food systems in climate change mitigation. This conference was attended by prime ministers and governors across the Dutch Caribbean.

5.3 RO 3 - RESEARCH ON FOOD PRODUCTION, SUPPLY, AND CONSUMPTION IN ARUBA, BONAIRE, AND CURACAO

Different aspects of food systems have been studied extensively in the ABC islands, as observed through the scoping review (chapter 4). It was observed that LCA was not often used to study the food systems of the ABC islands, except by the author or by students under supervision of the author. Thus, approaches by other authors to study sustainability will be reflected on. Since 2019, several studies were published using a water-energy-food nexus (WEF nexus) framework

(Martin del Campo et al., 2023; Debrot & van den Burg, 2019; Oliemans, 2019; van der Geest & Slijkerman, 2019). The WEF nexus was globally increasingly applied since 2011 and recognizes interdependencies among water, energy, and food systems, providing a holistic perspective that moves beyond silos (Al-Saidi & Elagib, 2017; Lv et al., 2023). In 2022, the term food sovereignty was first mentioned by van der Loo, who examined how food sovereignty can be protected in public policy and how it can be developed as a notion in international human rights law (van der Loo, 2022). Others focused on innovative technologies to reduce by-catch in fish catches (A. E. Johnson, 2010), on designing circular eco-feed chains for pork production (Broeze et al., 2020), or establishing local algae production (Chin-On et al., 2022), for example.

Given the intentional broadness of the sample, authors in different fields (e.g., health, sustainability, policies, food security) will draw different conclusions from the results of the scoping review. This section contains reflections based on personal observations which are divided in three sub-sections:

- Section 5.3.1: research on food security and local production
- Section 5.3.2: participatory action research (PAR)
- Section 5.3.3: solutions beyond academic research

5.3.1 Research on food security and local production

Food security and local production have always been important topics of discussion in the ABC islands. To the author's knowledge, the topic of agriculture, livestock and fisheries in the Dutch Caribbean was first researched in 1901 (van Kol, 1901), if not earlier. Throughout the 20th century, these sectors remained a topic of discussion (e.g., Dussel, 1912; Leupen, 1966; Zaneveld, 1944). Results from the scoping review showed an increase in studies focusing on food security since the COVID-19 pandemic, specifically on *food stability*. Also, policy makers and citizens have regularly expressed their interest and have initiated projects to increase local food production and consumption (e.g., Bon dia Aruba, 2023; Breukink, Eva, 2023; Szabó, 2025),

From 2000 – 2025, at least twenty-one studies have characterized the food systems of the ABC islands on a national level, with a focus on local food production, fisheries and/or food security (Table 5-2). Results showed that islands were often studied simultaneously with other islands in the Dutch Caribbean, especially grouped as the BES islands (Bonaire, Sint Eustatius, Saba) or the CAS islands (Curacao, Aruba, Sint Maarten). In Sint Maarten, additional research activities related to local agriculture and food security took place that were not captured through the scoping review (de Jong et al., 2024; Hoogstad et al., 2024), which focus' was on the ABC islands. However, it is imperative that islands within the Dutch Caribbean can learn from each other.

Numerous studies identified challenges and opportunities to increase local production and food security (e.g., de Jong et al., 2024; Post & Hengsdijk, 2023; van den Dungen, 2025), showing that these are well studied. The fisheries sector was often studied separately, probably due to its complex nature. A content analysis of 13 research activities within a research project on food security and economic diversification in Aruba, Curacao, and Sint Maarten, concluded that the four most pressing challenges identified were related to government, production materials and land, farming knowledge and collaboration, and consumer attitude (de Jong et al., 2024). The paragraphs below provide insight in these challenges, while additional details can be found in the articles mentioned in table 5-2.

Challenges related to *the government* included resistance to changing outdated laws, the lack of services, the lack of access to data, and a perceived lack of continuity and dedication. Lotz et al. (2020) also mentioned the need for a multi-year long-term approach with periodic quantitative monitoring and reporting. Issues reported in Bonaire included the lack of regulations to prevent the depletion of groundwater, and a regulation that prohibits commercial agricultural activities on areas that *were* designated as agricultural areas (Lotz et al., 2020).

Table 5-2 Publicly available research on national food production, fisheries and/or food security in the ABC islands, from 2000 – 2025

Abbreviations: Aruba (AW), Bonaire (BQ-BO), Saba (BQ-SA), Sint Eustatius (BQ-SE), Curacao (CW), Sint Maarten (SXM). *Studies not retrieved through the scoping review.

Reference	Title	Islands
(van den Dungen, 2025)*	Veldonderzoek in het kader van vergroten voedselzekerheid op Aruba , Curaçao en Sint Maarten: De visie van voedselproducenten over belemmeringen en kansen omtrent voedselproductie	AW CW SXM
(de Jong et al. 2024)	Being prepared for exogenous shocks: Exploring strategies to transform the food system of Curaçao, Aruba and Sint Maarten	AW CW SXM
(de Kort et al., 2024)	Island Innovation Policy Brief: Exploring amplified Food Security vulnerabilities in Curaçao, Aruba and Sint Maarten amidst the COVID-19 pandemic	AW CW SXM
(Moreno Ramirez, 2024)	Food Production and post COVID-19 Aruban food security	AW
(Sociaal Economische Raad, 2024)	Advies Voedselproductie op Aruba	AW
(Visser et al., 2024)	Curaçao Food Security before and during COVID-19; evaluation of the island's food Availability, Accessibility, and Stability	CW
(Hira et al., 2023)	Curaçao Food Security Assessment: Enhancing the Resilience of Vulnerable Households while Boosting Sustainable Economic Growth	CW
(Post & Hengsdijk, 2023)	Inventory and characterization of food systems on Bonaire	BQ-BO
(van Werkhoven, 2022)*	Food Security in Times of Crisis: The Impact of COVID-19 on Household Food Security in Curaçao	CW
(Boyer et al., 2020)	Building Resilience in Aruba's Food Security During the COVID-19 Pandemic and Beyond	AW

Table continues on next page

Reference	Title	Islands
(Lotz et al., 2020)*	Ontwikkelingsmogelijkheden voor de agrarische sector in Caribisch Nederland	BQ-BO BQ-SA BQ-SE
(Sociaal Economische Raad, 2020)	Advies voedselzekerheid op Aruba	AW
(WWF-Netherlands & Good Fish Foundation, 2020)*	Analysis of the seafood supply chain on Bonaire, Saba and St. Eustatius	BQ-BO BQ-SA BQ-SE
(Debrot & van den Burg, 2019)	Nexus interventions for small tropical islands: Case study Bonaire. Food from the Oceans	BQ-BO
(Mac Donald, 2019)	Mas Piska pa Boneiru: a social mapping study of the fisheries sectors of Bonaire, Saba and St. Eustatius	BQ-BO BQ-SA BQ-SE
(Pauly et al., 2015)*	Reconstruction of total marine catches for Aruba, southern Caribbean, 1950-2010	AW
(van der Geest & Slijkerman, 2019)	Nexus interventions for small tropical islands: case study Bonaire: Food from the Land	BQ-BO
(Vermeij et al., 2019)	Historical changes (1905-present) in catch size and composition reflect altering fisheries practices on a small Caribbean island	CW
(Kraan, 2017)	Frame Survey Curacao's fishing fleet 2016	CW
(Bogaardt et al., 2015)*	Voedselzekerheid op Bonaire, St. Eustatius en Saba. Aangrijpingspunten voor de beleidsinzet van het ministerie van Economische Zaken	BQ-BO BQ-SA BQ-SE
(Boekhoudt & Hadicurari, 2015)	Piscamento na Aruba. Fragil y bou presion; un parti cultural di nos cultura cu mester maneha pa sostenibilidad	AW

Challenges related to *production materials and land* included issues in land availability, the availability of affordable water, receiving agricultural loans, and high costs of materials such as fertilizers, animal feed, electricity, mulch or soil (de Jong et al., 2024; van den Dungen, 2025). High farming costs made it difficult to compete with lower priced food imports (de Jong et al., 2024; Lotz et al., 2020; Saint Ville et al., 2015; van den Dungen, 2025). In Bonaire, the shortage of water for agricultural purposes was experienced as the biggest constraint for growth of the agricultural sector (Lotz et al., 2020). Also, an adequate infrastructure for rainwater harvesting and distribution was lacking (de Jong et al., 2024; Lotz et al., 2020). Besides, not all land is suitable for agricultural production and not all land is protected from theft and free-roaming goats that damage the harvest (Bos et al., 2018; Lotz et al., 2020).

Challenges related to *farming knowledge and collaboration* included a lack of farming knowledge, knowledge sharing, and collaboration among farmers. On the one hand farmers were afraid of competition when sharing knowledge, on the other hand they were keen to share their experiences (de Jong et al., 2024; van den Dungen, 2025). A lack of knowledge may include knowledge on food processing to increase the profit and shelf-life of local produce, knowledge on improved sales channels to a wider public (Kock, 2013; Lotz et al., 2020), and knowledge about entrepreneurship and administration (van den Dungen, 2025). However, half of the farmers in Curacao indicated that they did not experience a lack of knowledge, and opinions on which type of knowledge is lacking are heterogeneous (van den Dungen, 2025). A related issue is the low attractiveness and image of the sector (Lotz et al., 2020).

Challenges related to *consumer attitude* included a lack of interest in fresh local produce due to unhealthy eating habits and a lack of cooking skills, illustrated through a preference for warm and fried foods, and the convenience of fast-food (de Jong et al., 2024). In Curacao, weekly fast-food consumption occurred for 65% and 41% of young adults (age 18 – 24) and adults, respectively. Daily soft drink consumption occurred for 48% and 29% of young adults and adults, respectively. While only a minority consumed sufficient fruits and vegetables (Verstraeten et al., 2017). Also, a preference for imported meats such as beef over local goat and sheep meat was observed in Curacao (van den Dungen, 2025).

Ample solutions which spread across different problem areas have been proposed in the same documents (see table 5-2) which mentioned the challenges above. To contribute to finding solutions to unhealthy eating habits and a low production and consumption of local products, two subjects will be explored in the following sections. Section 5.3.2 explores how the emerging method participatory action research (PAR) has been utilized in the ABC islands and may be applied in future research. Section 5.3.3 explores solutions beyond academic research.

5.3.2 Participatory Action Research (PAR)

Results from the scoping review showed an increase in participatory action research (PAR). "PAR seeks to understand and improve the world by changing it" (Baum et al., 2006). For example, Franken et al. (2025) performed an intervention in Aruba to nudge children to consume more water instead of sugar-sweetened beverages by using children as influencers and achieved positive results. Arias & de Droog (2021) tested the effect of self-education for diabetes patients to improve self-management in Aruba and received positive feedback from participants. Mac Donald (2019) established a new fisheries cooperative in Bonaire called PISKABON and formulated challenges in participatory fisheries management in Bonaire, Saba, and Sint Eustatius (BES islands). Van de Velde, (2022) participated in a community urban agriculture project called "Nos Mes Por" in Bonaire and developed guidelines to set up and design sustainable communal urban agriculture projects in Caribbean SIDS.

Robinson (2020) commented that action-based research, possibly outside the regular academe, may be required to locally adapt global solutions in SIDS. Ideas for future interventions which aim at the most pressing challenges in the ABC islands (see section 5.3.1) may be retrieved from literature or from international organizations (e.g., Brown et al., 2022; Fusi et al., 2025; Gupta et al., 2024; Haynes et al., 2022, 2025; WWF & Climate Focus, n.d.). Islands may need to tailor such global solutions to fit their unique and varying geographic, economic, and political characteristics and collaborations with local experts can assist in shaping more sustainable futures that fit in cultural contexts of small islands (Goilo, 2024; Havea et al., 2024; Robinson, 2020).

An example intervention retrieved through the scoping review of Haynes et al. (2025) focused on increasing fruit and vegetable consumption in the United States through the Double Up Food Bucks (DUFB) Program. Lower income households became eligible to receive twice the amount of fruits and vegetables at their local farmer markets. Results showed that the DUFB Program did not lead to a consistent higher fruit and vegetable intake and identified barriers in reaching participants with baseline low fruit and vegetables consumption (Atoloye et al., 2021).

5.3.3 Solutions beyond academic research

Although (academic) research can provide insights into current challenges and solutions for increased local production and food security, the role of entrepreneurship, good projects and strong governance should also be acknowledged (Guell et al., 2022). To illustrate the importance of projects and governance, in a BES island wide Nature and Environment Policy Plan Caribbean Netherlands (NEPP), several goals have been formulated, which included goals related to local food production, food security, and fisheries (Ministry of Agriculture, Nature and Food Quality et al., 2020). The progress report illustrated which projects are currently being executed and which projects were finalized.

To illustrate, the following projects have been accomplished: professionalizing the slaughterhouse to adhere to food safety regulations; procuring a plantation for the purpose of nature, agriculture, and recreation. The following projects are being executed: free fruit and vegetables for the food bank; creating jobs in the agricultural sector; providing agricultural training; and training of government employees in the agricultural sector on tillage and machine use (TwynstraGudde, 2024). Such progress reports, together with other documents such as conference reports from DCALFA (DCALFA, 2024, 2025), are also valuable sources – next to research documents – for policy makers, researchers, and other food system stakeholders.

The author also observed several activities on each island focused on promoting healthy local food production and consumption. Without aiming to be complete, examples of local activities are provided. In Aruba, Mondi Replika offers farm-to-table experiences and eco-conscious horticultural masterclasses. They collaborate with local farmers and focus on continuous menu innovation, such as pulled chicken from green soursop and vegan burgers based on *comcomber chicito* (local small cucumber) (Diamanta Kock, personal communication, September 28, 2025). Coincidentally, de Kort et al. (2023) identified the need for processing of *comcomber chicito* to diversify food value chains in Aruba. In Bonaire, the Nature Cooking School Bonaire teaches people to sustainability grow local products – using permaculture and food forests – and to cook plant-based nutritious dishes with local products, while reconnecting with nature during the outside-taught classes and workshops (Forbes, 2024). In Curacao, the Rotary Health Academy organizes a program to "empower as many Curaçaoans as possible with the knowledge and motivation to embrace a healthier lifestyle", including nutrition workshops, a supermarket safari, hands-on healthy cooking sessions, and promoting water consumption, among others (Rotary Club of Curacao, 2025).

Regional efforts in the Dutch Caribbean also aim to increase local production and food security. In 2022, the Dutch Caribbean Agriculture, Livestock, and Fisheries Alliance (DCALFA) was founded. Their members include the governments and public entities of the six Dutch Caribbean islands. "DCALFA fosters collaboration, knowledge exchange, and policy alignment across the six Dutch Caribbean islands. Their mission is to support local producers, strengthen food systems, and balance economic development with ecological responsibility" (DCALFA, 2025). Policies of other SIDS also stress a focus on food and nutrition security, including an increased production and availability of regionally produced foods (CARICOM, 2010; FAO, 2017; Hibi et al., 2018).

5.4 ACADEMIC CONTRIBUTIONS

This doctoral study focused on LCA as a method and made the following academic contributions to the field of food and LCA:

- The environmental impact of sea transport for an island's food imports was understudied and was therefore calculated in detail for a variety of supply chains. It was concluded that the environmental impact of sea transport for an island's food imports generally did not contribute much to the total environmental impact of products with relatively high GHG emissions, despite modelling details related to island characteristics. For products with relatively low GHG emissions – such as potatoes or onions – and long transport distances, sea transport may contribute to almost half of total GHG emissions.

- To the knowledge of the author, GHG emissions of air freighting food imports using specific passenger aircrafts had not been calculated before in the field of food and LCA. Results showed lower GHG emissions of airfreight when using aircraft characteristics of passenger aircrafts. Additionally, it was recommended to include the weight of the 80 kg AKE container to the model. This contribution is relevant for both countries and small islands, as dedicated air freighter routes concentrate on a few trade lanes, notably East Asia–North America and East Asia–Europe (Button, 2021). Thus, destinations further away from dedicated air freighter may utilize passenger aircrafts for (food) imports and may currently overestimate GHG emissions of airfreight.
- The representativeness of trade data regarding the countries of origin of vegetable imports was evaluated. The results indicated that relying solely on trade data may be insufficient for accurately assessing food import origins. Complementary data collection methods, such as supermarket visits, are likely necessary to obtain a more reliable and comprehensive understanding. Details are provided in section 1.1 of the supplementary materials of van Veghel et al. (2024).

Through the scoping review, the following academic contribution was made:

- A scoping review on research related to food production, supply, and consumption in the ABC islands was performed for the first time. This contributed to more transparency and may assist researchers, policy makers, and those interested from inside and outside the region to create fact-based policies and projects, to identify research gaps, and to define directions for future research.

5.5 FUTURE PERSPECTIVES

5.5.1 Global transitions, local effects

Willingly or unwillingly, islands are influenced by global changes. One of those is the rise in LCA-based food eco-labels, which show an on-label environmental score of products (Cicek et al., 2024). The question is if a product's eco-label score remains valid after exportation to the Dutch Caribbean. Although products with an ecolabel have not yet been observed in Aruban supermarkets (personal observations, September 27, 2025), products with labels related to the nutritional quality of food products, the Nutri-Score, have been observed in Aruba (personal observations, September 27, 2025). The Nutri-Score was launched in the Netherlands on January 1, 2024 and "is a front-of-pack label that provides information on the nutritional quality of products" (Santé publique France, 2025).

Cicek et al. (2024) analysed sixteen LCA-based ecolabelling schemes in Europe, including public as well as private schemes. One of those is from Inoqo, a company that calculated carbon footprint values for selected products of a leading Dutch grocery retailer (Inoqo, 2024). Those products may also be imported by Aruba or other Dutch Caribbean islands.

If a product's eco-label score remains valid after exportation to the Dutch Caribbean will depend on the product type and transportation modes used for importation. Differences between actual carbon footprints and carbon footprints depicted by foreign eco-labels are expected to be highest for products with a relatively low carbon footprint, products transported by air, or products that had a relatively long road transport step, while cooled transportation may further increase differences. For products with a relatively high carbon footprint, differences between actual carbon footprints and carbon footprints depicted by the foreign eco-label are expected to be low, unless the product was flown in.

Nonetheless, if products with carbon footprint ecolabels will be imported to Aruba, consumers may prefer those with lower GHG emissions. In 2023, a master thesis student from KU Leuven conducted a discrete choice experiment on consumer preferences for salmon in Aruba and found that providing information on GHG emissions had the potential to influence the behaviour of consumers and consumers preferred salmon with lower GHG emissions. However, the production method (fresh or frozen) was found to be more important than GHG emissions, and the country of origin was found to be equally important to GHG emissions (Van Opstal, 2023). It should be considered however that although eco-labels may be promising, differences in their methodologies, governance, and labelling systems were observed (Cicek et al., 2024) that potentially cause confusion among consumers.

5.5.2 The role of LCA in food security planning in the ABC islands

Given the importance of food security for the ABC islands (Antilliaans Dagblad, 2025; Szabó, 2025) and a growing interest in increasing local production (Rohling et al., 2025), LCA may play a supportive role in specific aspects of food security planning. The focus of LCA could be land use prognoses, water requirements, and the assessment of local environmental impacts due to fertilizer use, pesticide use, and outputs from farms.

To illustrate, land is often scarce in small islands, has competition from other sectors (S. S. Jurgens et al., 2024; Steward et al., 2024), and land ownership is complex and shaped by historical events and industrialization (Russel, 2024). Thus, it should be utilized as effectively as possible. Couwet et al. (2022) showed that the land needed to produce Curacao's food imports was more than four times the size of Curacao. Although not all imported foods can be produced in Curacao, this number implies the need to carefully plan agricultural land use when aiming to replace food imports by local production.

Moreover, some agricultural projects may cause unwanted side effects, such as ammonia production by chicken farms or manure production of livestock. In 2018, a business plan was designed to import thousand cows to Curacao and five ministers signed a Memorandum of Understanding to show their interest in supporting this project (Antilliaans Dagblad, 2018). The project was eventually not executed. If such projects are initiated in the future, LCA can be used to quantify possible side effects. To the knowledge of the author, LCA was not yet used to assess the environmental impact of current local production, although students did express their interest in this topic (Falcon, 2024; Hesseling, 2025).

5.5.3 Recommendations for future research

Future research should find solutions for the challenges to increase local food production and food security as well as provide insight in locally acceptable dietary changes aimed at climate change mitigation. Recommendations for future research mentioned in the general discussion are:

- Section 5.2.3: gain insight into GHG emissions of national food supply and define options to adjust food consumption to lower GHG emissions of the food supply, which is likely higher than the global average. This may be done in parallel with quantifying GHG emissions of locally consumed recipes and diets.
- Section 5.3.1: focus on challenges in increasing food production and consumption, and increasing food security, in relation to the four most mentioned challenges as mentioned by de Jong et al. (2024): government, production materials and land, farming knowledge and collaboration, and consumer attitude.
- Section 5.3.2: further explore utilizing participatory action research to test interventions that lead to increased local food production and consumption, increased food security, and healthier diets.
- Section 5.5.2: utilize LCA in food security planning to quantify future land and water needs and investigate the environmental impact of (potential) local farming techniques focusing for example on pesticide and fertilizer use.
- Present the scoping review to policy makers and other food system stakeholders and explore how a continuous mapping of research on food production, supply, and consumption can benefit them. This may lead to narrowing down the scope and broadening the database selection.

5.6 CONCLUSION

This dissertation focused on quantifying the environmental impact of an island's food imports and mapping existing research on food production, supply, and consumption in the ABC islands. The environmental impact of three brands of canned tuna imports and five types of vegetable imports (from 25 product-country combinations) was quantified. Although differences between canned tuna brands were minimal, sea freighted vegetable imports clearly had lower GHG emissions compared to those that were air freighted, especially when road transport was relatively short.

Although sea transport was modelled in detail for both case studies, considering island characteristics, it generally did not contribute much to the environmental impact of food imports. GHG emissions of air transport were previously overestimated by using generic models for GHG emissions of airfreight. It is recommended to LCA practitioners to use application-specific aircraft characteristics to quantify GHG emissions of air freight and to include the 80 kg AKE container in which products are airfreighted.

Current research on food production, supply, and consumption in the ABC islands shows a growing research field, a diverse local and international research community, a strong Dutch Kingdom and EU orientation in collaboration and funding, and a diverse coverage of food related topics and aspects of the food system studied. The quantity of research on food security increased since the COVID-19 pandemic. Challenges and solutions for increasing local food production and improving food security are well documented. LCA may assist in specific aspects of food security planning, as part of a greater puzzle. In the opinion of the author, future research, as well as projects and governance, should focus on solutions for the challenges in increasing local food production and food security, as well as provide insight in locally acceptable dietary changes aimed at climate change mitigation and health.

PART V

REFERENCES

Aircraft Commerce. (2008). *Aircraft Operator's & Owner's Guide: A330-200 & -300 specifications*. 300–302.

Akkermans, L., Quartel, H., Bell, H., Ustasia, R., Fliervoet, J., & Witteveen, L. (2024). *Food resilient futures in the Caribbean Netherlands. Bonaire, Saba, St. Eustatius*. https://issuu.com/loeswitteveen/docs/18_okt_24_-_d2.3_research_report_-_final?fr=xKAE9_zU1NQ

Alberts, A. (2020). *Small Island Tourism Economies and the tourism area lifecycle: Why Aruba and Sint Maarten have exceeded their carrying capacity* [Doctoral dissertation, University of Amsterdam]. https://dare.uva.nl/search?identifier=67446c6f-950d-4738-8b5a-6f1082924523

Al-Saidi, M., & Elagib, N. A. (2017). Towards understanding the integrative approach of the water, energy and food nexus. *Science of The Total Environment*, *574*, 1131–1139. https://doi.org/10.1016/j.scitotenv.2016.09.046

Amato-Ali, C.-Y., Iese, V., Mekala, G., Hidalgo, D., & Sakiti-Waqa, H. (2025). *Food loss in Pacific Island Countries: A scoping review of the literature*. *8*. https://doi.org/10.3389/fsufs.2024.1520335

Antilliaans Dagblad. (2018). *Duizend koeien naar Bándariba*. https://antilliaansdagblad.com/nieuws-menu/17237-duizend-koeien-naar-bandariba

Antilliaans Dagblad. (2025). Voedselzekerheid cruciaal. *Jaargang 22 Nr. 212*.

Arias, N., & de Droog, M. (2021). *Effectivity study of PRISMA Aruba. A self-management education program for adults with type 2 diabetes in Aruba*. https://hdl.handle.net/20.500.14473/1181

Aruba Fair Trade Authority. (2024). *Food Products Market Study: A study on the prices and market structure in the food sector in Aruba*. https://www.afta.aw/marktonderzoek-voedingsmiddelen/

Asselin-Balençon, A., Broekema, R., Teulon, H., Gastaldi, G., Houssier, J., Moutia, A., Rousseau, V., Wermeille, A., & Colomb, V. (2020). *AGRIBALYSE v3.0: The French agricultural and food LCI database. Methodology for the food products*. (ADEME, Ed.). https://doc.agribalyse.fr/documentation-en/agribalyse-data/documentation

Atkinson, S. (2020). Environmentally friendly sea-water reverse osmosis technology produces drinking water for island inhabitants. *Membrane Technology*, *2020*(4), 6–6. https://doi.org/10.1016/S0958-2118(20)30068-9

Atoloye, A. T., Savoie-Roskos, M., & Durward, C. M. (2021). *Higher Fruit and Vegetable Intake Is Associated with Participation in the Double Up Food Bucks (DUFB) Program*. *13*(8). https://doi.org/10.3390/nu13082607

Avadí, A., Bolaños, C., Sandoval, I., & Ycaza, C. (2015). Life cycle assessment of Ecuadorian processed tuna. *International Journal of Life Cycle Assessment*, *20*(10), 1415–1428. https://doi.org/10.1007/s11367-015-0943-2

Avadí, A., Fréon, P., & Quispe, I. (2014). Environmental assessment of Peruvian anchoveta food products: Is less refined better? *International Journal of Life Cycle Assessment*, *19*(6), 1276–1293. https://doi.org/10.1007/s11367-014-0737-y

Avadí, A., & Vázquez-Rowe, I. (2019). Life Cycle Inventories of Wild Capture and Aquaculture. *Ecoinvent Report*, (May).

AXSMarine. (2022). *Alphaliner Top 100*. https://alphaliner.axsmarine.com/PublicTop100/

Babiker, M., Berndes, G., Blok, K., Cohen, B., Cowie, A., Geden, O., Ginzburg, V., Leip, A., Smith, P., Sugiyama, M., & Yamba, F. (2022). Cross-sectoral perspectives. In P. R. Shukla, J. Skea, R. Slade, A. A. Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC. https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-12/

Bant, J., Mijts, E., & Scholing, P. (2025). Diaspora and Digital Discourse: Papiamento/u Research in the Digital Archives of Coleccion Aruba. *Archipelagos*, (8). https://archipelagosjournal.org/issue08/bant-diaspora.html

Barten, R. J. P., Wijffels, R. H., & Barbosa, M. J. (2020). Bioprospecting and characterization of temperature tolerant microalgae from Bonaire. *Algal Research*, *50*. https://doi.org/10.1016/j.algal.2020.102008

Baum, F., MacDougall, C., & Smith, D. (2006). Participatory action research. *Journal of Epidemiology & Community Health*, *60*(10), 854–857. https://doi.org/10.1136/jech.2004.028662

Beazley, R., Ciardi, F., & Bailey, S. (2020). *Shock-Responsive Social Protection in the Caribbean Synthesis Report*. World Food Programme; Oxford Policy Management. https://www.wfp.org/publications/research-programme-shock-responsive-social-protection-caribbean

Bekhoven, J. van, Berg, S. van den, Strijbosch, J., & Floren, Z. (2023). Quantitative and Qualitative data on agricultural fields in Aruba: An interdisciplinary paper analyzing Aruba's agricultural soil quality and the relationships between local farmers and Santa Rosa. In E. Mijts, J. Ballentyne, & C. Rodriguez (Eds), *UAUCU Student research exchange collected papers 2023* (pp. 187–205). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1062

Bell, E. M., & Horvath, A. (2020). Modeling the carbon footprint of fresh produce: Effects of transportation, localness, and seasonality on US orange markets. *Environmental Research Letters*, *15*(3), 34040–34040. https://doi.org/10.1088/1748-9326/ab6c2f

Benini, L., Mancini, L., Sala, S., Manfredi, S., Schau, E. M., & Pant, R. (2014). *Normalisation method and data for Environmental Footprints* (p. 150). https://doi.org/10.2788/16415

Bilotkach, V. (2021). Air Cargo. In R. Vickerman (Ed.), *International Encyclopedia of Transportation* (pp. 258–262). Elsevier. https://doi.org/10.4324/9781315566375-24

Blakeway, R. D., Jones, G. A., & Boekhoudt, B. (2019). Controlling lionfishes (Pterois spp.) with consumption: Survey data from Aruba demonstrate acceptance of non-native lionfishes on the menu and in seafood markets. *Fisheries Management and Ecology*, *27*(3), 227–230. https://doi.org/10.1111/fme.12404

Bleukx, K., Janssens, D., Vandenbergh, J., & Vankrunkelsven, E. (2021). *Carbon 'Foodprint' of Aruba's Food Imports* [Bachelor thesis, KU Leuven]. https://hdl.handle.net/20.500.14473/1306

Blom, E.-A. (2024). Herding Profits: Factors affecting Goat Commercialisation amidst Grazing Constraints in Aruba. In E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research Exchange: Collected Papers 2024* (9th edn, pp. 41–50). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1063

Boekhoudt, B. G. & Hadicurari. (2015). *Piscamento na Aruba 2012*. https://issuu.com/byron.boekhoudt/docs/piscamento_2013_v13jmar13/1%0A

Bogaardt, M.-J., De Jong, R., & Van Der Heide, M. (2015). *Voedselzekerheid op Bonaire, St. Eustatius en Saba. Aangrijpingspunten voor de beleidsinzet van het ministerie van Economische Zaken* (No. 2282700090; pp. 34–34). https://edepot.wur.nl/360979

Bohnes, F. A., Hauschild, M. Z., Schlundt, J., & Laurent, A. (2019). Life cycle assessments of aquaculture systems: A critical review of reported findings with recommendations for policy and system development. *Reviews in Aquaculture*, *11*(4), 1061–1079. https://doi.org/10.1111/raq.12280

Bohnes, F. A., & Laurent, A. (2021). Environmental impacts of existing and future aquaculture production: Comparison of technologies and feed options in Singapore. *Aquaculture*, *532*(September 2020), 736001–736001. https://doi.org/10.1016/j.aquaculture.2020.736001

Bokern, P., & Fernandez Beiro, L. (2025). *Young people in the Caribbean Netherlands: Student survey results*. https://www.cbs.nl/en-gb/longread/statistische-trends/2025/young-people-in-the-caribbean-netherlands-student-survey-results

Bon dia Aruba. (2023, December 13). *Ministerio di naturalesa ta lansa proyecto di agricultura cu 13 Scol*. https://www.bondia.com/ministerio-di-naturalesa-ta-lansa-proyecto-di-agricultura-cu-13-scol1/

Bonnélye, V., Sanz, M. A., Francisci, L., Beltran, F., Cremer, G., Colcuera, R., & Laraudogoitia, J. (2007). *Curacao, Netherlands Antilles: A successful example of boron removal on a seawater desalination plant*. 200–205. https://doi.org/10.1016/j.desal.2006.04.045

Borman, G. D., de Boef, W. S., Dirks, F., Gonzalez, Y. S., Subedi, A., Thijssen, M. H., Jacobs, J., Schrader, T., Boyd, S., ten Hove, H. J., van der Maden, E., Koomen, I., Assibey-Yeboah, S., Moussa, C., Uzamukunda, A., Daburon, A., Ndambi, A., van Vugt, S., Guijt, J., … van Berkum, S. (2022). Putting food systems thinking into practice: Integrating agricultural sectors into a multi-level analytical framework. *Global Food Security*, *32*(November 2021), 100591–100591. https://doi.org/10.1016/j.gfs.2021.100591

Bos, A. P., Neijenhuis, F., Pourier, S., & Almenkerk, J. J. van. (2018). *Plan van aanpak Geprofessionaliseerde Geitenhouderij op Bonaire*. https://research.wur.nl/en/publications/plan-van-aanpak-geprofessionaliseerde-geitenhouderij-op-bonaire/

Boyer, M., Horton, J., Millán María, F., Grosjean, C. F. R., Arias, R. E., Lopez, E. M., Wrede, P., de Kort, R. E., Justiniano, I., & Chapman. (2020). *Building Resilience in Aruba's Food Security During the COVID-19 Pandemic and Beyond*. https://hdl.handle.net/10986/38506

BP. (2022). *Bp Statistical Review of World Energy*. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

Branthomme, A., Merle, C., Kindgard, A., Lourenço, A., Ng, W.-T., D'Annunzio, R., & Shapiro, A. (2023). *How much do large-scale and small-scale farming contribute to global deforestation? Results from a remote sensing pilot approach* (No. 9789251378427). https://doi.org/10.4060/cc5723en

Breukink, Eva. (2023). Voedselbos brengt wijkbewoners Ser'i Otrobanda dichter bij elkaar. *Caribisch Netwerk*. https://caribischnetwerk.ntr.nl/2023/08/05/voedselbos-brengt-wijkbewoners-seri-otrobanda-dichter-bij-elkaar/

Broeze, J., Soethoudt, H., Hogeveen, E., Dwarkasing, A., & Bruschke, C. (2020). *Circular Eco-feed chain for responsible pork consumption and production at Curaçao. A first exploration*. https://doi.org/10.18174/515344

Brouwer, N.-L., Kaya, J., & Vermeeren, R. (2019). *Onderzoek naar handelsbelemmeringen en -kansen t.a.v. Voedselzekerheid in Caribisch Nederland*. Netherlands Enterprise Agency.

Brown, C. R., Rocke, K., Murphy, M. M., & Hambleton, I. R. (2022). Interventions and policies aimed at improving nutrition in Small Island Developing States: A rapid review. *Revista Panamericana de Salud Pública*, *46*, 1. https://doi.org/10.26633/RPSP.2022.33

Brugulat-Panés, A., Guell, C., Unwin, N., Martin-Pintado, C., Iese, V., Augustus, E., & Foley, L. (2025). *Examining Food Sources and Their Interconnections over Time in Small Island Developing States: A Systematic Scoping Review.* https://doi.org/10.3390/nu17142353

Button, K. (2021). Airfreight and Economic Development. In R. Vickerman (Ed.), *International Encyclopedia of Transportation: Volume 1-7* (Vol. 3, pp. 355–360). Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10269-6

Caribbean Feeder Services. (2022). *Schedules*. https://www.caribbeanfeeder.com/

CARICOM. (2010). *CARICOM Regional Food and Nutrition Security Policy*. https://caricom.org/documents/regional-food-and-nutrition-security-policy/

Carmona Baez, A., Echteld, E., & Mijts, E. (2021). *COVID-19, Food Security and Economic Diversity in Curaçao, Aruba and Sint Maarten* (University of Aruba & the Metabolism of Islands, Organizers) [Conference Presentation]. Sustainable Island Futures II. https://hdl.handle.net/20.500.14473/1333

Casey, L., Freeman, B., Francis, K., Brychkova, G., McKeown, P., Spillane, C., Bezrukov, A., Zaworotko, M., & Styles, D. (2022). Comparative environmental footprints of lettuce supplied by hydroponic controlled-environment agriculture and field-based supply chains. *Journal of Cleaner Production*, *369*. https://doi.org/10.1016/j.jclepro.2022.133214

Caspers, J., Coroama, V. C., Sadetzky, L., Süßbauer, E., & Finkbeiner, M. (2023). Measuring the climate change impact of household food and beverage packaging—A life cycle assessment of a living lab. *Sustainable Production and Consumption*, *42*, 259–267. https://doi.org/10.1016/j.spc.2023.10.002

CBS. (2020). *Invoer groente en fruit Caribisch Nederland, 2018-2019*. https://www.cbs.nl/nl-nl/maatwerk/2020/37/invoer-groente-en-fruit-caribisch-nederland-2018-2019

CBS. (2025). *Caribbean NL: lifestyle; personal characteristics* [Data set]. https://opendata.cbs.nl/#/CBS/en/dataset/82292ENG/table?dl=E137

CBS Aruba. (2019). *Income and Expenditure Survey 2016*. https://cbs.aw/wp/index.php/2019/04/04/income-expenditure-survey-2016/

Center for Environmental Farming Systems. (2016). *Estimated Rows and Acres of Production Per Case and Pallet at Wholesale, Select Crops*. https://cefs.ncsu.edu/resources/estimated-rows-and-acres-of-production-per-case-and-pallet-at-wholesale-select-crops-2/

Chaudhary, A., & Krishna, V. (2019). Country-Specific Sustainable Diets Using Optimization Algorithm. *Environmental Science & Technology*, *53*(13), 7694–7703. https://doi.org/10.1021/ACS.EST.8B06923

Chicken of the Sea. (2020). *Trace your seafood, can code: 02/17/2414B*. https://trace.chickenofthesea.com/a/ryCn4sx9?code=undefined&utm_source=site

Chimi, P. M., Nkoué, B. B., Kamdem, M. E. K., Pokam, E. Y. N., Ngamsou, K. A., Yonga, G., Osso, D. B., & Mala, W. A. (2025). Trends in agricultural sustainability research: A 40-year bibliometric review. *Discover Environment*, *3*. https://doi.org/10.1007/s44274-025-00269-9

Chin-On, R. C. (2021). *Stand-alone production of microalgae on Bonaire for food, feed, chemicals, and fuels* [Conference presentation]. Dutch Caribbean Research Week.

Chin-On, R. C., Barbosa, M. J., Wijffels, R. H., & Janssen, M. (2022). A novel V-shaped photobioreactor design for microalgae cultivation at low latitudes: Modelling biomass productivities of Chlorella sorokiniana on Bonaire. *Chemical Engineering Journal*, *449*. https://doi.org/10.1016/j.cej.2022.137793

Chukalla, A. D., Mekonnen, M. M., Gunathilake, D., Wolkeba, F. T., Gunasekara, B., & Vanham, D. (2025). Global spatially explicit crop water consumption shows an overall increase of 9% for 46 agricultural crops from 2010 to 2020. *Nature Food*. https://doi.org/10.1038/s43016-025-01231-x

Cicek, S., Boone, K., & Broekema, R. (2024). *State of the art analysis of LCA-based ecolabelling schemes in Europe* (pp. 1–58). https://edepot.wur.nl/680057%0Ahttps://doi.org/10.18174/680057

Clark, M., Springmann, M., Rayner, M., Scarborough, P., Hill, J., Tilman, D., Macdiarmid, J. I., Fanzo, J., Bandy, L., & Harrington, R. A. (2022). Estimating the environmental impacts of 57,000 food products. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(33). https://doi.org/10.1073/pnas.2120584119

Clune, S., Crossin, E., & Verghese, K. (2017). Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production*, *140*, 766–783. https://doi.org/10.1016/j.jclepro.2016.04.082

CMA CGM. (2022a). *CMA CGM Eco Calculator*. https://www.cma-cgm.com/ebusiness/schedules/eco-calculator

CMA CGM. (2022b). *CMA CGM Schedules*. https://www.cma-cgm.com/ebusiness/schedules/routing-finder

Coelman, I. (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 E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research Exchange Collected Papers 2024* (9th edn, pp. 147–162). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1063

Connell, J., Lowitt, K., Saint Ville, A., & Hickey, G. M. (2020). Food Security and Sovereignty in Small Island Developing States: Contemporary Crises and Challenges. In J. Connell & K. Lowitt (Eds), *Food Security in Small Island States* (pp. 1–23). Springer. https://doi.org/10.1007/978-981-13-8256-7_1

Couwet, E., Tombeur, J., van Hoof, S., & Vanhee, Y. (2022). *Bepalen van de milieu-impact van Curaçao's import van voedsel en dranken* [Bachelor thesis, KU Leuven]. https://hdl.handle.net/20.500.14473/1305

Criens, S.R. (1985). *Literatuuroverzicht van de Nederlandse Antillen* (7th edn). Stichting voor Culturele Samenwerking.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

Croes, N. (2016). *Seawater agriculture: The feasibility study of an application in Aruba* [Bachelor thesis]. University of Curacao.

Curiel, J. (2000). *Independent smal-scale drinking water production in Curacao using solar energy* [Bachelor thesis]. University of Curacao.

da Costa Figueira, K. M. (2005). *A feasibility study for a shrimp farming company in Curacao* [Bachelor Thesis]. University of Curacao.

Daal, A. (2021). *Kuenta di mi tera: Historia di 500 aña di agrikultura na Kòrsou*. Pumbo.nl B.V.

Daal, D., Benjamin, B., Hepple, J., Kok, P., & Garmers, T. (2021). *The Strategic Tourism Destination Development Plan 2022–2026*. https://www.curacaotouristboard.com/island-developments/master-plan/

Davidson, B. C., Philpot, S., Onyeokoro, U., Jones, W., Amelingmeier, L., Kamel, J., & Madhavan, R. (2013). Assessment of the degree of mercury contamination of marine fish around Bonaire. *Toxicological and Environmental Chemistry*, *95*(10), 1675–1679. https://doi.org/10.1080/02772248.2014.904126

Davydenko, I. Y., Hopman, W. M. M., & Smokers, R. T. M. (2020). *Carbon Footprinting of Combined Passenger Freight Operations in Aviation Networks*. https://doi.org/10.13140/RG.2.2.13364.58240

DCALFA. (2024). *1st Meeting of the Dutch Caribbean Agriculture, Livestock & Fisheries Alliance. Conference Report. Bridging Islands – Cultivating Growth*.

DCALFA. (2025). *2nd DCALFA Conference*. https://dcalfa.com/wp-content/uploads/2025/07/Conference-Report.pdf

de Jong, R., Hoogstad, E., Visser, B., de Kort, R., Carmona Báez, A., Echteld, E., Mijts, E., & De. (2024). Being prepared for exogenous shocks: Exploring strategies to transform the food system of Curaçao, Aruba and Sint Maarten. In N. Faraclas, R. Severing, E. Echteld, S. Delgado, & W. Rutgers (Eds), *Southern Entanglements: Southern Epistemologies, Southern Praxes and The Languages, Literatures and Cultures of the Dutch Caribbean and Beyond* (Vol. 1, pp. 13–28). University of Curaçao/University of Puerto Rico. https://islandsinbetween.com/2023-volume-1/

de Kort, R., Jong, R. D., Hoogstad, E., Carmona Báez, A., Echteld, E., & Mijts, E. (2024). *Island Innovation Policy Brief: Exploring amplified Food Security vulnerabilities in Curacao , Aruba and Sint Maarten amidst the COVID-19* *pandemic*. https://islandinnovation.co/policy-papers/exploring-amplified-food-security-vulnerabilities-in-curacao-aruba-and-sint-maarten-amidst-the-covid-19-pandemic/

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, S. Delgado, & W. Rutgers (Eds), *Southern Entanglements: Southern Epistemologies, Southern Praxes and The Languages, Literatures and Cultures of the Dutch Caribbean and Beyond* (Vol. 1, pp. 53–70). University of Curaçao/University of Puerto Rico. https://islandsinbetween.com/2023-volume-1/

De Vlieghere, A. (2022). *Life cycle assessment of imported seafood in Aruba* [Master thesis, KU Leuven]. https://hdl.handle.net/20.500.14473/1309

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

DEACI. (2025). *Prices and Regulations*. https://www.deaci.aw/prices-and-regulations/

Debrot, D., & van den Burg, S. (2019). *Nexus interventions for small tropical islands: Case study Bonaire. Food from the Oceans*. https://edepot.wur.nl/471564

Dengerink, J., & Brouwer, H. (2020). *Food system models and methodologies within Wageningen University & Research: Opportunities for deepening our food systems work* (pp. 24–24). https://edepot.wur.nl/516691

Diaconeasa, M. C., Zaharia, A., Lădaru, G. R., & Mocanu, S. (2024). Bibliometric Analysis of Sustainable Food Systems. *Amfiteatru Economic*, *26*(Special Issue No. 18), 1224–1240. https://doi.org/10.24818/EA/2024/S18/1224

Diaz-Maroto Knöfler, Y. (2024). An exploratory paper: Societal gaps for a transformation towards sustainable rainwater harvesting in Aruba. In *UAUCU Student Research Exchange: Collected Papers 2024* (pp. 177–184). https://hdl.handle.net/20.500.14473/1063

DiPietro, R. B., Levitt, J. A., Taylor, S., & Nierop, T. (2019). First-time and repeat tourists' perceptions of authentic Aruban restaurants: An importance-performance competitor analysis. *Journal of Destination Marketing and*

Management, *14*(June), 100366–100366. https://doi.org/10.1016/j.jdmm.2019.100366

Dussel, G. B. (1912). *Kort overzicht over de landbouw op Curaçao*. Commissie voor de koloniale landbouwtenstoonstelling. http://hdl.handle.net/1887.1/item:388246

EEA. (1995). *Europe's Environment—The Dobris Assessment*. https://www.eea.europa.eu/downloads/548ab8ca81896a1667ad4df28f6fc3bf/1606129171/page037new.html.pdf

EMLEG. (2018). *Vietnam – heavy duty vehicles*. https://www.emleg.com/legislation/view/vietnam-heavy-duty-vehicles

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change*, *18*, 234–245. https://doi.org/10.1016/j.gloenvcha.2007.09.002

European Commission. (2017). *PEFCR Guidance document—Guidance for Product Environmental Footprint Category Rules (PEFCRs), version 6.3* (PEFCR Guidance Document). https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf

European Commission, Joint Research Centre, & Institute for Environment and Sustainability. (2010). *International Reference Life Cycle Data System (ILCD) Handbook—General guide for Life Cycle Assessment—Detailed Guidance*. https://doi.org/10.2788/38479

European Union Aviation Safety Agency. (2023). *Type-Certificate Data Sheet No. EASA.A.004 for Airbus A330*. https://www.easa.europa.eu/en/document-library/type-certificates/noise/easaa004-airbus-a330

Facun, K. (2021). *Vertical Farming, the practice of cultivating plants on a stacked layer to optimize space* (University of Aruba & the Metabolism of Islands, Organizers) [Conference Presentation]. Sustainable Island Futures II. https://hdl.handle.net/20.500.14473/1333

Falcon, A. (2024). Unveiling Hotspots in Hydroponic Lettuce Production. In E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research Exchange Collected Papers 2024* (9th edn, pp. 71–78). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1063

FAO. (2016). *State of Food Security and Nutrition in Small Island Developing States (SIDS)*. https://openknowledge.fao.org/handle/20.500.14283/i5327e

FAO. (2017). *Global Action Programme on Food Security and Nutrition in Small Island Developing States* (1st edn). FAO. https://openknowledge.fao.org/handle/20.500.14283/i7297en

FAO. (2020). *The state of world fisheries and aquaculture 2020: Sustainability in action*. https://doi.org/10.4060/ca9229en

FAO. (2021). *GLOBEFISH Highlights 3rd issue 2021, with Jan.–Mar. 2021 Statistics – International Markets on Fisheries and Aquaculture Products* (No. 9789251351154; Quarterly Update. Globefish Highlights No. 3–2021). https://doi.org/10.4060/cb7153en

FAO. (2023). *Loss and damage in agrifood systems: Addressing gaps and challenges* (No. 9789251384046). https://doi.org/10.4060/cc8810en

FAO. (2025). *FAOSTAT: Data*. https://www.fao.org/faostat/en/#data

FAO, IFAD, UNICEF, WFP, & WHO. (2021). *The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all*. https://doi.org/10.4060/cb5409en

Farmery, A., Gardner, C., Green, B. S., & Jennings, S. (2014). Managing fisheries for environmental performance: The effects of marine resource decision-making on the footprint of seafood. *Journal of Cleaner Production*, *64*, 368–376. https://doi.org/10.1016/j.jclepro.2013.10.016

Fazio, S., Castellani, V., Sala, S., Schau, E., Secchi, M., Zampori, L., & Diaconu E. (2018). *JRC Technical reports. Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment method. New models and differences with ILCD Contents*. https://doi.org/10.2760/671368

Federal Aviation Administration. (2013). *Type Certificate Data Sheet E41NE*. https://drs.faa.gov/search

Forbes. (2024). *How Bonaire Is Fighting To Keep Its Number One Tourist Attraction*. https://www.forbes.com/sites/christopherelliott/2024/04/14/how-bonaire-is-fighting-to-keep-its-number-one-tourist-attraction/

Franken, S. C. M., Smit, C. R., & Buijzen, M. (2018). Promoting water consumption on a caribbean island: An intervention using children's social networks at schools. *International Journal of Environmental Research and Public Health*, *15*(4). https://doi.org/10.3390/ijerph15040713

Franken, S. C. M., Smit, C. R., de Leeuw, R. N. H., van Woudenberg, T. J., Burk, W. J., Bevelander, K. E., & Buijzen, M. (2023). Understanding the behavioral determinants of adolescents' water consumption: A cross-country comparative study. *Dialogues in Health*, *2*. https://doi.org/10.1016/j.dialog.2023.100101

Franken, S. C. M., Smit, C. R., de Moor, M. H. M., de Leeuw, R. N. H., & Buijzen, M. (2025). Promoting water consumption among children through a social network intervention: A cluster randomized controlled trial on a Caribbean island. *Journal of Public Health - Heidelberg*. https://doi.org/10.1007/s10389-024-02386-w

Frankowska, A., Jeswani, H. K., & Azapagic, A. (2019). Environmental impacts of vegetables consumption in the UK. *Science of the Total Environment*, *682*, 80–105. https://doi.org/10.1016/j.scitotenv.2019.04.424

Freja. (2023). *LD3/AKE/AVE Container*. https://www.freja.com/transport-and-logistics-solutions/air-freight/ld3-ake-ave-container/

Frischknecht, R., Braunschweig, A., Hofstetter, P., & Suter, P. (2000). Human health damages due to ionising radiation in life cycle impact assessment. *Environmental Impact Assessment Review*, *20*(2), 159–189. https://doi.org/10.1016/S0195-9255(99)00042-6

Fusi, S. K. F., Gómez-Donoso, C., Backholer, K., Browne, J., Ferguson, M., & Cameron, A. J. (2025). Food environments in the Pacific region and efforts to improve them: A scoping review. *Public Health Nutrition*, *28*(1). https://doi.org/10.1017/S1368980024002350

Georgeou, N., Hawksley, C., Wali, N., Lountain, S., Rowe, E., West, C., & Barratt, L. (2022). Food security and small holder farming in Pacific Island countries and territories: A scoping review. *PLOS Sustainability and Transformation*, *1*(4). https://doi.org/10.1371/journal.pstr.0000009

Gerber, P. J., Steinfield, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falucci, A., & Tempio, G. (2013). *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities* (No. 9789251079201). Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/4/i3437e/i3437e.pdf

Giordana, L. (2024). Food sovereignty from the point of view of “Overseas Europe”: Aruba, Saint-Pierre and Miquelon, Belep (New Caledonia). *Archivio Antropologico Mediterraneo*, *26*(1). https://doi.org/10.4000/11t6k

Gobierno Aruba. (2025). *National Survey: “What Are We Eating?” continues*. https://www.gobierno.aw/en/national-survey-what-are-we-eating-continues

Goilo, J.-C. M. E. (2024). *Information actors beyond modernity and coloniality in times of climate change: A comparative design ethnography on the making* *of monitors for sustainable futures in Curaçao and Amsterdam, between 2019-2022* [Doctoral dissertation, University of Amsterdam]. https://pure.uva.nl/ws/files/152634052/2024_01_17_Full-Thesis-los.pdf

Goossens, Y., Berrens, P., Custers, K., Van Hemelryck, S., Kellens, K., & Geeraerd, A. (2019). How origin, packaging and seasonality determine the environmental impact of apples, magnified by food waste and losses. *International Journal of Life Cycle Assessment*, *24*(4), 667–687. https://doi.org/10.1007/s11367-018-1522-0

Goossens, Y., & Schmidt, T. G. (2025). Mind the method! A systematic literature review of the methodological choices used to assess the environmental impacts of diets. *Cleaner Environmental Systems*, *18*(100289). https://doi.org/10.1016/j.cesys.2025.100289

Government of the Netherlands. (2025). *What are the different parts of the Kingdom of the Netherlands?* https://www.government.nl/topics/caribbean-parts-of-the-kingdom/question-and-answer/what-are-the-different-parts-of-the-kingdom-of-the-netherlands

Graver, B., Zhang, K., & Rutherford, D. (2019). *CO2 emissions from commercial aviation, 2018* [Working paper]. International Council on Clean Transportation. https://theicct.org/publication/co2-emissions-from-commercial-aviation-2018/

Grêaux, K., Schwiebbe, L., Renders, C. M., Doak, C. M., Visser, R., Holthe, J. K., & HiraSing, R. A. (2013). Breastfeeding and food pattern in overweight children in the Caribbean. *Paediatrics and International Child Health*, *33*(1), 18–22. https://doi.org/10.1179/2046905512Y.0000000048

Greenhouse Gas Protocol. (n.d.). *GaBi Databases*. Retrieved https://ghgprotocol.org/gabi-databases

Grydehøj, A. (2023). No future of island studies: Embracing island studies in plural. *Island Studies Journal*, *18*(1), 295–305. https://doi.org/10.24043/isj.421

Guell, C., Brown, C. R., Navunicagi, O. W., Iese, V., Badrie, N., Wairiu, M., Saint Ville, A., Unwin, N., Kiran, S., Samuels, T. A., Hambleton, I., Tukuitonga, C., Donato-Hunt, C., Kroll, F., Nugent, R., Forouhi, N. G., Benjamin-Neelon, S., & the Community Food and Health (CFaH) team. (2022). Perspectives on strengthening local food systems in Small Island Developing States. *Food Security*, *14*(5), 1227–1240. https://doi.org/10.1007/s12571-022-01281-0

Gupta, A., Huggins, C. E., Sacks, G., Gittelsohn, J., & Peeters, A. (2024). A systematic review of the implementation of healthy food retail interventions in settings with multiple food retail outlets (complex food retail settings). *Journal of Nutritional Science*, *13*, e31. https://doi.org/10.1017/jns.2024.52

Gustavsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2013). *The methodology of the FAO study: "Global Food Losses and Food Waste—Extent, causes and prevention"-FAO,2011* (No. 9789172903234; pp. 1–70). http://www.diva-portal.org/smash/get/diva2:944159/FULLTEXT01.pdf

Habibe, N. (2019). *The import costs of fruits and vegetables on Aruba, mitigating the volatility of prices to ensure sustainable supply* [Bachelor thesis, University of Aruba]. https://hdl.handle.net/20.500.14473/888

Halpern, B. S., Cottrell, R. S., Blanchard, J. L., Bouwman, L., Froehlich, H. E., Gephart, J. A., Jacobsen, N. S., Kuempel, C. D., McIntyre, P. B., Metian, M., Moran, D. D., Nash, K. L., Többen, J., & Williams, D. R. (2019). Putting all foods on the same table: Achieving sustainable food systems requires full accounting. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(37), 18152–18156. https://doi.org/10.1073/pnas.1913308116

Hassan, S., Nguyen, M., Buchanan, M., Grimshaw, A., Adams, O. P., Hassell, T., Ragster, L., & Nunez-Smith, M. (2020). Management of chronic noncommunicable diseases after natural disasters in the caribbean: A scoping review. *Health Affairs*, *39*(12), 2136–2143. https://doi.org/10.1377/hlthaff.2020.01119

Hauschild, M. Z. (2018a). Introduction to LCA Methodology. In M. Z. Hauschild, R. K. Rosenbaum, & S. Irving Olsen (Eds), *Life Cyc*. Springer Nature. https://doi.org/10.1007/978-3-319-56475-3_6

Hauschild, M. Z. (2018b). *Life Cycle Assessment: Theory and Practice* (M. Z. Hauschild, R. K. Rosenbaum, & S. I. Olsen, Eds; pp. 59–66). Springer Nature. https://doi.org/10.1007/978-3-319-56475-3

Havea, P. H., Su, B., Liu, C., Kundzewicz, Z. W., Wang, Y., Wang, G., Jing, C., Jiang, H., Yang, F., Mata'afa, F. N., & Jiang, T. (2024). Wind and solar energy in Small Island Developing States for mitigating global climate change. *iScience*, *27*(10), 1–12. https://doi.org/10.1016/j.isci.2024.111062

Haynes, E., Augustus, E., Brown, C. R., Guell, C., Iese, V., Jia, L., Morrissey, K., & Unwin, N. (2022). Interventions in Small Island Developing States to improve diet, with a focus on the consumption of local, nutritious foods: A systematic review. *BMJ Nutrition, Prevention and Health*, *5*(2), 243–253. https://doi.org/10.1136/bmjnph-2021-000410

Haynes, E., Brown, C. R., Halliday, C., Alcantara, L., Cayetano, C., Creencia, L., Gajardo, L. J., Goodwin, A., Guell, C., Howitt, C., Iese, V., Karley, A., Madarcos, J. R., Madarcos, K., Morrissey, K., Patel, K., Sobers, N., Veisa, F., Murphy, M. M., & Unwin, N. (2025). Interventions designed to promote the consumption of locally produced foods: A scoping review. *Frontiers in Sustainable Food Systems*, *9*. https://doi.org/10.3389/fsufs.2025.1544092

Haynes, E., Brown, C. R., Wou, C., Vogliano, C., Guell, C., & Unwin, N. (2018). Health and other impacts of community food production in small island developing states: A systematic scoping review. *Revista Panamericana de Salud Publica/Pan American Journal of Public Health*, *42*, 1–9. https://doi.org/10.26633/RPSP.2018.176

Hernández-Moreno, A., Vásquez-Palma, O., Gutiérrez-Gutiérrez, F., Cordero-Ahiman, O., Celedón-Celis, N., & Hochstetter-Diez, J. (2024). Analysis of Food Security of Older Rural Indigenous People in Latin America and the Caribbean. *Foods*, *13*(11), 1–24. https://doi.org/10.3390/foods13111772

Hesseling, P. (2025). A Critical Assessment of the Feasibility of Sustainable Aquafarming on Aruba: A Deep Dive into the Carbon Footprint and Eutrophication Potential. In E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research Exchange: Collected Papers 2025* (10th edn). University of Aruba and University College Utrecht. https://students.uu.nl/sites/default/files/UAUCUU - VOLUME 2025.pdf

Hibi, E., Lam, F., & Chopin, F. (2018). *Accelerating Action on Food Security and Nutrition in Pacific Small Island Developing States (SIDS)*. https://openknowledge.fao.org/handle/20.500.14283/mv748en

Hierro, O., Gallejones, P., Besga, G., Artetxe, A., & Garbisu, C. (2021). A Comparison of IPCC Guidelines and Allocation Methods to Estimate the Environmental Impact of Barley Production in the Basque Country through Life Cycle Assessment (LCA). *Agriculture*, *11*, 1005. https://doi.org/10.3390/agriculture11101005

Hira, C., Wielinga, D., Boyer, M., Horton, J., Millán, M., de Kort, R. E., Justiniano, I., & van Baren, P. (2023). *Curaçao Food Security Assessment: Enhancing the Resilience of Vulnerable Households while Boosting Sustainable Economic Growth*. http://documents.worldbank.org/curated/en/099062023124510570

HLPE. (2014). *Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition* *of the Committee on World Food Security*. http://www.fao.org/3/a-i3901e.pdf

HLPE. (2017). *Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security* (pp. 150–150). http://www.fao.org/3/a-i7846e.pdf

HLPE. (2020). *Food security and nutrition: Building a global narrative towards 2030. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. https://www.fao.org/3/ca9731en/ca9731en.pdf

Hoekstra, A. Y., & Mekonnen, M. M. (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(9), 3232–3237. https://doi.org/10.1073/pnas.1109936109

Hoogenboom, R. L. A. P., Dam, G. T., van Leeuwen, S. P. J., van Egmond, H., Nicolina, J., & Dwarkasing, A. J. S. (2021). High levels of dioxins and PCBs in meat, fat and livers of free ranging pigs, goats, sheep and cows from the island of Curaçao. *Chemosphere*, *263*. https://doi.org/10.1016/j.chemosphere.2020.128057

Hoogstad, E., Carmona Báez, A., Echteld, E., & Mijts, E. (2024). Investigating Challenges and Opportunities in Developing Local Agriculture Food Production Systems in St. Martin: A Complex Adaptive Systems Analysis. In N. Faraclas, R. Severing, E. Echteld, S. Delgado, & W. Rutgers (Eds), *Southern Entanglements: Southern Epistemologies, Southern Praxes and The Languages, Literatures and Cultures of the Dutch Caribbean and Beyond* (Vol. 1, pp. 29–52). University of Curaçao/University of Puerto Rico. https://islandsinbetween.com/2023-volume-1/

Hospido, A., Vazquez, M. E., Cuevas, A., Feijoo, G., & Moreira, M. T. (2006). Environmental assessment of canned tuna manufacture with a life-cycle perspective. *Resources, Conservation and Recycling*, *47*(1), 56–72. https://doi.org/10.1016/j.resconrec.2005.10.003

ICAO. (2018). *ICAO Carbon Emissions Calculator Methodology Version 11*. https://www.icao.int/environmental-protection/CarbonOffset/Pages/Default.aspx

ICAO. (2022). *ICAO CORSIA CO2 Estimation and Reporting Tool (CERT)*. https://www.icao.int/CORSIA/CERT

Ingram, J. (2011). A food systems approach to researching food security and its interactions with global environmental change. *Food Security*, *3*, 417–431. https://doi.org/10.1007/s12571-011-0149-9

Inoqo. (2024). *Albert Heijn Becomes First Grocery Retailer Globally to Share Ingredient-Level Product Climate Footprint with Consumers*. https://www.inoqo.com/blog/albert-heijn-becomes-first-grocery-retailer-globally-to-share-ingredient-level-product-climate-footprint-with-consumers

International Air Transport Association. (2022a). *IATA Recommended Practice 1678: Cargo CO2 Emissions Measurement Methodology*. https://www.iata.org/en/programs/cargo/sustainability/carbon-footprint/

International Air Transport Association. (2022b). *IATA Recommended Practice 1726:Passenger CO2 Calculation Methodology*. https://www.iata.org/en/programs/environment/passenger-emissions-methodology/#tab-1

International Monetary Fund. Western Hemisphere Dept. (2019). *Kingdom of the Netherlands—Aruba: 2019 Article IV Consultation Discussions—Press Release and Staff Report* (IMF Staff Country Reports 2019). https://doi.org/10.5089/9781498318006.002

International Trade Center. (2020). *List of products imported to Aruba. Detailed products in the following category: 07 Edible vegetables and certain roots and tubers*. www.trademap.org

IPCC. (1992). *Climate change: The IPCC 1990 and 1992 Assessments* (No. 0662198212; The World Environment 1972–1992). https://www.ipcc.ch/report/climate-change-the-ipcc-1990-and-1992-assessments/

IPCC. (2006). Volume 4: Agriculture, Forestry, and Other Land Use. Chapter 10: Emissions from Livestock and Manure Management. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. https://www.ipcc.ch/report/ar5/wg1/

IPCC. (2019). *Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. https://www.ipcc.ch/srccl/

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 (No. 9781009157896). https://doi.org/10.1017/9781009157896

IPCC. (2023). Section 2: Current Status and Trends. In *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (First, pp. 42–66). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647

Iribarren, S., Stonbraker, S., Larsen, B., Santos, I., Faria, R., Góes, F. S. N., Binfa, L., & Larson, E. (2018). Clinical nursing and midwifery research in Latin American and Caribbean countries: A scoping review. *International Journal of Nursing Practice*, *24*(2), 1–12. https://doi.org/10.1111/ijn.12623

ISO. (2006a). *ISO: Environmental management—Life cycle assessment—Principles and framework (ISO 14040)*.

ISO. (2006b). *ISO: Environmental management—Life cycle assessment—Requirements and guidelines (ISO 14044)*.

JBI. (2015). *The Joanna Briggs Institute Reviewers' Manual 2015: Methodology for JBI scoping reviews* (pp. 1–24). https://reben.com.br/revista/wp-content/uploads/2020/10/Scoping.pdf

Johnson, A. E. (2010). Reducing bycatch in coral reef trap fisheries: Escape gaps as a step towards sustainability. *Marine Ecology Progress Series*, *415*, 201–209. https://doi.org/10.3354/meps08762

Johnson, J. (2024). *Reviving cultural historical water management practices for nature-based solutions* [Conference Presentation]. Dutch Caribbean Research Week.

Jolliet, O. (2022). Integrating Dietary Impacts in Food Life Cycle Assessment. *Frontiers in Nutrition*, *9*, 898180. https://doi.org/10.3389/fnut.2022.898180

JSTOR. (2025). *De West-Indische Gids*. https://www.jstor.org/journal/westindigids

Jungbluth, N., & Meili, C. (2019). Recommendations for calculation of the global warming potential of aviation including the radiative forcing index. *International Journal of Life Cycle Assessment*, *24*, 404–411. https://doi.org/10.1007/s11367-018-1556-3

Jurgens, S. (2020). *Spatial Analysis of Urban Metabolism in Small Island States* (University of Aruba & the Metabolism of Islands, Organizers) [Conference Presentation]. Sustainable Island Futures I. https://hdl.handle.net/20.500.14473/1339

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

Kabinet van de Gevolmachtigde Minister van Aruba. (n.d.). *Energie*. Retrieved 11 February 2026, from https://www.kabinetaruba.nl/onderwerpen/energie

Kesse-Guyot, E., Pointereau, P., Brunin, J., Perraud, E., Toujgani, H., Berthy, F., Allès, B., Touvier, M., Lairon, D., Mariotti, F., Baudry, J., & Fouillet, H. (2023). Trade-offs between blue water use and greenhouse gas emissions related to food systems: An optimization study for French adults. *Sustainable Production and Consumption*, *42*(September), 33–43. https://doi.org/10.1016/j.spc.2023.09.008

Kim-Hak, D., Dixon, M. B., Galan, M. A., Boisseau, F., Gallastegui, J., & Martina, R. (2015). Santa Barbara, Curacao desalination plant expansion using NanoH2O thin film nanocomposite (TFN) SWRO membrane. *Desalination and Water Treatment*, *55*(9), 2446–2452. https://doi.org/10.1080/19443994.2014.939859

Kingdom of the Netherlands. (2024). *King's Day 2024*. https://www.netherlandsandyou.nl/web/united-kingdom/w/king-s-day-2024

Klein, A., Hilster, D., Scholten, P., van Wijngaardn, L., Tol, E., & Otten, M. (2021). *STREAM Freight Transport 2020: Emissions of freight transport modes*. https://cedelft.eu/publications/stream-freight-transport-2020/

Klein, J., Geilenkirchen, G., Hulskotte, J., Hensema, A., Fortuin, P., & Molnár-in 't Veld, H. (2012a). *Methods for calculating the emissions of transport in the Netherlands (April)*.

Klein, J., Geilenkirchen, G., Hulskotte, J., Hensema, A., Fortuin, P., & Molnár-in 't Veld, H. (2012b). *The emissions of transport in the Netherlands*.

KLM. (2017). *KLM 2017 Annual Report*. https://www.klm.nl/en/information/corporate/publications

KLM. (2019). *KLM 2019 Annual Report* (No. 1111301593678). https://www.klm.nl/en/information/corporate/publications

Koblianska, I., Kalachevska, L., & Schlauderer, R. (2024). Agricultural Life Cycle Assessment: A system-wide bibliometric research. *Agricultural and Resource Economics*, *10*(1). https://doi.org/10.22004/ag.econ.341553

Kock, M. (2013). *The Development Of An Eco-gastronomic Tourism (egt) Supply* [Doctoral dissertation, University of Central Florida]. https://stars.library.ucf.edu/etd/2760/

Koolman, R. (2015). *The Taste of Aruba: The Influence of Aruba's Food on the Tourist's Travel Experience: Culinary Tourism* [Bachelor thesis]. NHTV Breda University of Applied Sciences.

Kraan, M. (2017). *Frame survey, Curaçao's fishing fleet 2016* (C022/17). Wageningen Marine Research. https://edepot.wur.nl/413272

KU Leuven. (2024). *Information Retrieval*. https://bib.kuleuven.be/english/research/information-retrieval

Kummu, M., Kinnunen, P., Lehikoinen, E., Porkka, M., Queiroz, C., Röös, E., Troell, M., & Weil, C. (2020). Interplay of trade and food system resilience: Gains on supply diversity over time at the cost of trade independency. *Global Food Security*, *24*, 100360. https://doi.org/10.1016/j.gfs.2020.100360

Lan, X., & Keeling, R. (2026). *Mauna Loa CO2 annual mean data* [Data set]. NOAA/GML. https://gml.noaa.gov/ccgg/trends/data.html

Lathuillière, M. J., Flach, R., Wang-erlandsson, L., Ribeiro, V., zu Ermgassen, E. K. H. J., & Souza Jr, C. M. (2025). *Data for 'International reliance on Brazil's water through soy and beef supply chains' (v.1)*. https://doi.org/10.5281/zenodo.14921618

Laurent, A., & Hauschild, M. Z. (Eds). (2015). Normalization. In *Life Cycle Impact Assessment* (pp. 271–300). Springer Science+Business Media B.V. https://doi.org/10.1007/978-94-017-9744-3

Lelièvre-Damit, J. (2022). *Life cycle analysis of chicken in the Aruban food basket* [Master thesis, KU Leuven]. https://hdl.handle.net/20.500.14473/1308

Leupen, F. F. (1966). *Landbouw en veeteelt op de benedenwindse eilanden*. Het kabinet van de Vice-Minister President.

Lincoln Lenderking, H., Robinson, S. ann, & Carlson, G. (2021). Climate change and food security in Caribbean small island developing states: Challenges and strategies. *iScience*, *28*(3), 238–245. https://doi.org/10.1080/13504509.2020.1804477

Local2030 Islands Network. (2025). *Island Members*. https://www.islands2030.org/island-members

Loken, B., Opperman, J., Orr, S., Fleckenstein, M., Halevy, S., McFeely, P., Park, S., & Weber, C. (2020). *Bending the Curve: The Restorative Planet-Based Diets*. https://www.worldwildlife.org/publications/bending-the-curve-the-restorative-power-of-planet-based-diets/

Lotz, L. A. P., Debrot, A. O., Neijenhuis, F., Stanghellini, C., & Jongschaap, R. E. E. (2020). *Ontwikkelingsmogelijkheden voor de agrarische sector in Caribisch Nederland*. https://doi.org/10.18174/536176

Lucas, E., Galán-Martín, Á., Pozo, C., Guo, M., & Guillén-Gosálbez, G. (2021). Global environmental and nutritional assessment of national food supply patterns: Insights from a data envelopment analysis approach. *Science of the Total Environment*, *755*, 142826–142826. https://doi.org/10.1016/j.scitotenv.2020.142826

Lv, Y., Yuan, M., Zhou, X., Wang, Y., & Qu, X. (2023). The water-energy-food nexus: A systematic bibliometric analysis. *Environmental Science and Pollution Research International*, *30*(58), 121354–121369. https://doi.org/10.1007/s11356-023-29863-1

Mac Donald, S. (2019). *Mas Piska pa Boneiru: A social mapping study of the fisheries sectors of Bonaire, Saba and St. Eustatius* (Mas Piska Pa Boneiru: A Social Mapping Study of the Fisheries Sectors of Bonaire, Saba and St. Eustatius). https://www.academia.edu/41996891/MAS_PISKA_PA_BONEIRU_A_social_mapping_study_of_the_fisheries_sectors_of_Bonaire_Saba_and_St_Eustatius

Mak, M., van Buiren, K., & Nanne, J. (2025). *Balancing Growth: Tourism, Nature, and Heritage on Bonaire*. https://economisch-bureau.nl/wp-content/uploads/2025/05/tourism_impactstudy_Bonaire_BONHATA_EBA_final_report.pdf

Maritime Impact. (2020). *Ticket to trade: Increasing deadweight for improved efficiency*. https://www.dnv.com/expert-story/maritime-impact/Ticket-to-trade-increasing-deadweight-for-improved-efficiency/#:~:text=The-lower-density-of-water,in-summer-than-in-winter

Marrero, A., Anderson, E., De La Vega, C., Beltran, V., Haneuse, S., Golden, C., & Mattei, J. (2022). An integrated assessment of environmental sustainability and nutrient availability of food consumption patterns in Latin America and the Caribbean. *American Journal of Clinical Nutrition*, *116*(5), 1265–1277. https://doi.org/10.1093/ajcn/nqac220

Martin del Campo, F., Singh, S. J., & Mijts, E. (2023). The resource (in)sufficiency of the Caribbean: Analyzing socio-metabolic risks (SMR) of water, energy, and food. *Frontiers in Climate*, *5*. https://doi.org/10.3389/fclim.2023.1085740

McElroy, J. L., & Parry, C. E. (2010). The characteristics of small island tourist economies. *Tourism and Hospitality Research*, *10*, 315-328-315–328. https://doi.org/10.1057/thr.2010.11

Mehlhart, C. (2020). The Ocean Paradox: Values Held by Resource Users in Aruba' Fisheries. In E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research*

Exchange: Collected Papers 2020. University of Aruba & University College Utrecht. https://hdl.handle.net/20.500.14473/1060

Mengyu, L., Nanfei, J., Lenzen, M., Malik, A., Liyuan, W., Yutong, J., & Raubenheimer, D. (2022). Global food-miles account for nearly 20% of total food-systems emissions. *Nat Food*, *3*, 445–453. https://doi.org/10.1038/s43016-022-00531-w

Michalský, M., & Hooda, P. S. (2015). Greenhouse gas emissions of imported and locally produced fruit and vegetable commodities: A quantitative assessment. *Environmental Science & Policy*, (48), 32–43. https://doi.org/10.1016/j.envsci.2014.12.018

Mickleburgh, H. L., & Laffoon, J. E. (2018). *Assessing dietary and subsistence transitions on prehistoric Aruba: Preliminary bioarchaeological evidence* (p. 306). https://doi.org/10.4324/9781351169202-13

Mijts, E., & Ballantyne, J. (Eds). (2024). *UAUCU Student Research Exchange: Collected Papers 2024* (9th edn). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1063

Mijts, E., & Ballantyne, J. (Eds). (2025). *UAUCU Student Research Exchange Collected Papers 2025* (10th edn). University of Aruba and University College Utrecht. https://students.uu.nl/sites/default/files/UAUCUU - VOLUME 2025.pdf

Milà i Canals, L., Muñoz, I., Hospido, A., Plassmann, K., & McLaren, S. (2008). *Life Cycle Assessment (LCA) of domestic vs. Imported vegetables. Case studies on broccoli, salad crops and green beans* (Nos 1464–8083; ISSN 1464-8083, pp. 46–46). http://www2.surrey.ac.uk/ces/files/pdf/0108_CES_WP_RELU_Integ_LCA_local_vs_global_vegs.pdf

Ministry of Agriculture, Nature and Food Quality, Ministry of Infrastructure and Water Management, & Ministry of Interior and Kingdom Relation. (2020). *Plan For Land & Water: Nature and Environment Policy Plan Caribbean Netherlands 2020—2030*. https://nl.chm-cbd.net/sites/nl/files/2021-05/NMBP_Caribbean%20Netherlands_Engels.pdf

Ministry of Economic Affairs, Communication and Sustainable Development. (2023). *Aruba's Transition to a Sustainable & Inclusive Economic Model*. https://www.gobierno.aw/nl/arubas-transition-to-a-sustainable-inclusive-economic-model

Ministry of Tourism and Public Health, Department of Public Health of Aruba, & Pan American Health Organization. (2024). *Pan American STEPS Risk*

Factor Surveillance Survey Aruba 2023 Report. https://dvg.aw/wp-content/uploads/2024/06/STEPS-report-Aruba-2023.pdf

Mohammadi, E., Singh, S. J., McCordic, C., & Pittman, J. (2022). Food Security Challenges and Options in the Caribbean: Insights from a Scoping Review. *Anthropocene Science*, *1*(1), 91–108. https://doi.org/10.1007/s44177-021-00008-8

Moreno Ramirez, A. (2024). *Food Production and post COVID-19 Aruban food security* [Bachelor thesis, University of Aruba]. https://hdl.handle.net/20.500.14473/1092

National Marine Fisheries Service. (2021). *Fisheries of the United States, 2019* (Issue NOAA Current Fishery Statistics No. 2019). https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-united-states

Nguyen, H., Randall, M., & Lewis, A. (2024). Factors Affecting Crop Prices in the Context of Climate Change—A Review. *Agriculture (Switzerland)*, *14*(135). https://doi.org/10.3390/agriculture14010135

Nieuw, C. (2021). *Two Birds, One Stone: Reducing Food waste While Feeding Aruba; Exploratory Research on how the Introduction of a Food Sharing app can Reduce Food Waste and Feed the Aruban Community with Surplus Food* [Bachelor Thesis, University of Aruba]. https://hdl.handle.net/20.500.14473/896%0A

Noal Farm. (2018). *Frozen tuna processing line in factory—Tuna processing and packing*. https://www.youtube.com/watch?v=C_7QNaAivMQ

Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. *Journal of Cleaner Production*, *140*, 399–409. https://doi.org/10.1016/j.jclepro.2016.06.071

Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., & Sala, S. (2017). Environmental impacts of food consumption in Europe. *Journal of Cleaner Production*, *140*, 753–765. https://doi.org/10.1016/j.jclepro.2016.06.080

NWO. (2025). *Caribbean Research Agenda*. https://www.nwo.nl/en/researchprogrammes/caribbean-research-a-multidisciplinary-approach/caribbean-research-agenda

Obispo, S. (2024). Food drying and food security: The case of the Aruban mango. In E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research Exchange Collected Papers 2024* (9th edn, pp. 125–132). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1063

OEC. (2024). *Aruba*. https://oec.world/en/profile/country/abw

Oliemans, J. B. (2019). *Strategies for integrated governance of the water-energy-food nexus in Bonaire* [Master thesis, TU Delft]. https://repository.tudelft.nl/file/File_5924288d-5e54-4b3c-ac4e-8307b38917ed?preview=1

O'Neill, F. G., & Ivanovic, A. (2016). The physical impact of towed demersal fishing gears on soft sediments. *ICES Journal of Marine Science*, (Suppl1), i5–i14. https://doi.org/10.1093/icesjms/fsv125

Oosterwolde, L. D. (2021). *Organizational resilience within the Food and Beverage sector of Aruba: A qualitative research exploring resilience during the COVID-19 Pandemic* [Bachelor thesis, University of Aruba]. https://hdl.handle.net/20.500.14473/901

Palacios, E., van Beukering, P. P. J. H., van Zanten, B., Lacle, F., Schep, S., & Soellner, I. (2021). Linking ecosystem services and the Sustainable Development Goals in Small Island Developing States: The case of Aruba. *One Ecosystem*, *6*. https://doi.org/10.3897/oneeco.6.e71033

PalNet GmbH Air Cargo Products. (2023). *LD3/AKE Container*. https://www.air-cargo-products.de/ld3-container.html

Parker, R. W. R., & Tyedmers, P. H. (2015). Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, *16*(4), 684–696. https://doi.org/10.1111/faf.12087

Pauly, D., Ramdeen, S., & Ulman, A. (2015). Reconstruction of total marine catches for Aruba, southern Caribbean, 1950-2010. *Working Paper Series*. https://www.seaaroundus.org/doc/publications/wp/2015/Pauly-et-al-Aruba.pdf

Pelletier, N., & Tyedmers, P. (2007). Feeding farmed salmon: Is organic better? *Aquaculture*, *272*(1–4), 399–416. https://doi.org/10.1016/j.aquaculture.2007.06.024

Peltzer, K., & Pengpid, S. (2020). *Skipping breakfast and its association with health risk behaviour and mental health among school-going adolescents in Curaçao: A cross-sectional national study* (p. 183).

Pengpid, S., & Peltzer, K. (2020a). Behavioural risk factors of non-communicable diseases among school-going adolescents in Curaçao: A cross-sectional national study. *Adolescence in Curaçao*, *12*(3), 335–342. https://doi.org/10.2147/IJGM.S226633

Pengpid, S., & Peltzer, K. (2020b). *Prevalence and associated factors of skipping breakfast among school-going adolescents in Curaçao: A cross-sectional national study*. *Adolescence in Curaçao*, *12*(3), 305–312.

Pérez-Neira, D., Copena, D., Armengot, L., & Simón, X. (2020). Transportation can cancel out the ecological advantages of producing organic cacao: The carbon footprint of the globalized agrifood system of ecuadorian chocolate. *Journal of Environmental Management*, *276*. https://doi.org/10.1016/j.jenvman.2020.111306

Perignon, M., & Darmon, N. (2021). Advantages and limitations of the methodological approaches used to study dietary shifts towards improved nutrition and sustainability. *Nutrition Reviews*, *80*(3), 579–597. https://doi.org/10.1093/nutrit/nuab091

Peters, M. D. J., Godfrey, C., McInerney, P., Khalil, H., Larsen, P., Marnie, C., Pollock, D., Tricco, A. C., & Munn, Z. (2022). Best practice guidance and reporting items for the development of scoping review protocols. *JBI Evidence Synthesis*, *20*(4), 953–968. https://doi.org/10.11124/JBIES-21-00242

Peters, M. D. J., Godfrey, C., McInerney, P., Munn, Z., Tricco, A. C., & Khalil, H. (2020). Chapter 11: Scoping Reviews (2020 version). In E. Aromataris & Z. Munn (Eds), *JBI Reviewer's Manual*. JBI. https://doi.org/10.46658/JBIRM-20-01

Pin, R. R., & van Heijningen, S. (2025). *Mapping the academic community of the ABCSSS Islands: Research report*. RE-Quest Research & Consultancy. https://www.requestcaribbean.com/_files/ugd/15a2bc_93ad837c4ffe47 17a48e1426119e42b8.pdf

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, *360*, 987–992. https://doi.org/10.1126/science.aaq0216

Porkka, M., Kummu, M., Siebert, S., & Varis, O. (2013). From Food Insufficiency towards Trade Dependency: A Historical Analysis of Global Food Availability. *PLoS ONE*, *8*(12), e82714. https://doi.org/10.1371/journal.pone.0082714

Post, P. P., & Hengsdijk, H. (2023). *Inventory and characterization of food systems on Bonaire* (Report WPR-1281). Wageningen Research. https://edepot.wur.nl/638960

PRé. (2025). *Our Story*. https://pre-sustainability.com/about/our-story/

Pruijs, M. (2022). *Agroecology for Local Resilience: Can Food Forests bear the fruit for achieving Food Sovereignty in Curaçao* [Master thesis, University of

Amsterdam]. https://openresearch.amsterdam/image/2022/11/23/final_document_pdf_thesis_mijke_pruijs_august_15th_2022.pdf

Ramírez-Cando, L. J., Mora-Ochoa, Y. I., Freire-Sanchez, A. S., & Medina-Rodriguez, B. X. (2025). Life Cycle Sustainability Assessment of Agriproducts in Latin America: Overview Based on Latent Dirichlet Allocation. *Sustainability (Switzerland)*, *17*(11), 1–16. https://doi.org/10.3390/su17114954

Ramos Monzón, M. (2024). Sustainable Water Governance: Exploring Political Factors Shaping Rainwater Harvesting Implementation in Aruba. In E. Mijts & J. Ballantyne (Eds), *UAUCU Student Research Exchange: Collected Papers 2024* (9th edn, pp. 201–206). University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1063

Rezaei, E. E., Webber, H., Asseng, S., Boote, K., Durand, J. L., Ewert, F., Martre, P., & MacCarthy, D. S. (2025). Climate change impacts on crop yields. *Nature Reviews Earth & Environment*, *4*(12), 831–846. https://doi.org/10.1038/s43017-023-00491-0

Rincon-Bravo, V. (2021). *Targeting Non-Communicable Diseases Risk Factor in Aruba: An analysis of the hindering and stimulating factors of effective policy implementation to target Non-communicable diseases risk factors in Aruba* [Bachelor thesis, University of Aruba]. https://hdl.handle.net/20.500.14473/897

Ritger, A. L., Curtis, A. N., & Chen, C. Y. (2018). Bioaccumulation of mercury and other metal contaminants in invasive lionfish (Pterois volitans/miles) from Curaçao. *Mar Pollut Bull.*, *131*(A), 38–44. https://doi.org/10.1016/j.marpolbul.2018.03.035.Bioaccumulation

Robinson, S. ann. (2020). Climate change adaptation in SIDS: A systematic review of the literature pre and post the IPCC Fifth Assessment Report. *Wiley Interdisciplinary Reviews: Climate Change*, *11*(4), 1–21. https://doi.org/10.1002/wcc.653

Rockström, J., Thilsted, S. H., Willett, W. C., Gordon, L. J., Herrero, M., Hicks, C. C., Mason-D'Croz, D., Rao, N., Springmann, M., Wright, E. C., Agustina, R., Bajaj, S., Bunge, A. C., Carducci, B., Conti, C., Covic, N., Fanzo, J., Forouhi, N. G., Gibson, M. F., … DeClerck, F. (2025). The EAT–Lancet Commission on healthy, sustainable, and just food systems. *The Lancet*, *406*(10512), 1625–1700. https://doi.org/10.1016/S0140-6736(25)01201-2

Roibás, L., Rodríguez-García, S., Valdramidis, V. P., & Hospido, A. (2018). The relevance of supply chain characteristics in GHG emissions: The carbon footprint of Maltese juices. *Food Research International*, *107*, 747–754. https://doi.org/10.1016/j.foodres.2018.02.067

Rosenbaum, R. K., Hauschild, M. Z., Boulay, A.-M., Fantke, P., Laurent, A., Núñez, M., & Vieira, M. (2018). Life Cycle Impact Assessment. In M. Z. Hauschild, R. K. Rosenbaum, & S. Irving Olsen (Eds), *Life Cycle Assessment: Theory and Practice*. Springer Nature. https://doi.org/10.1007/978-3-319-56475-3_10

Rotary Club of Curacao. (2025). *Rotary Health Academy*. https://www.rotarycuracao.org/page/rotary-health-academy

Ruiz-Salmón, I., Laso, J., Margallo, M., Villanueva-Rey, P., Rodríguez, E., Quinteiro, P., Dias, A. C., Almeida, C., Nunes, M. L., Marques, A., Cortés, A., Moreira, M. T., Feijoo, G., Loubet, P., Sonnemann, G., Morse, A. P., Cooney, R., Clifford, E., Regueiro, L., ... Aldaco, R. (2021). Life cycle assessment of fish and seafood processed products – A review of methodologies and new challenges. *Science of the Total Environment*, *761*(December 2020), 144094–144094. https://doi.org/10.1016/j.scitotenv.2020.144094

Russel, R. S. (2024). *Curaçao, Land and Property: Land ownership distribution in contemporary Curaçao, Dutch Caribbean, as of 2023* [Bachelor thesis, University Institute of Lisbon]. https://repositorio.iscte-iul.pt/handle/10071/32624?locale=en

Saint Ville, A. S., Hickey, G. M., & Phillip, L. E. (2015). Addressing food and nutrition insecurity in the Caribbean through domestic smallholder farming system innovation. *Regional Environmental Change*, *15*(7), 1325–1339. https://doi.org/10.1007/s10113-015-0770-9

Santé publique France. (2025). *Nutri-Score—Questions & Answers*. https://open.overheid.nl/documenten/d48cc86e-4134-4eda-8124-595f4e74047b/file

Schwiebbe, L., van Rest, J., Verhagen, E., Visser, R. W. M., Kist-van Holthe, J., & Hirasing, R. A. (2011). Childhood obesity in the Caribbean. *West Indian Medical Journal*, *60*(4), 442–445. https://pubmed.ncbi.nlm.nih.gov/22097675/

Seferidou, E., Knippenberg, S., & Laffoon, J. E. (2023). Reconstructing past lifeways of Indigenous individuals in pre-colonial Bonaire, through multi-isotope analysis. *Journal of Island and Coastal Archaeology*. https://doi.org/10.1080/15564894.2023.2289190

Semerel, J., John, N., Dehaen, W., & Fardim, P. (2023). Valorization of Aloe barbadensis Miller. (Aloe vera) Processing Waste. *Journal of Renewable Materials*, *11*(3), 1031–1061. https://doi.org/10.32604/jrm.2022.023449

Shah, P., Geyik, Ö., Archibald, C. L., & Hadjikakou, M. (2024). Sustainable food choices require product-specific environmental footprints: The case of packaged food in Australia. *Sustainable Production and Consumption*, *49*(July), 362–371. https://doi.org/10.1016/j.spc.2024.07.002

Shrivastava, C., Crenna, E., Schudel, S., Shoji, K., Onwude, D., Hischier, R., & Defraeye, T. (2022). To Wrap Or to Not Wrap Cucumbers? *Frontiers in Sustainable Food Systems*, *6*, 1–9. https://doi.org/10.3389/fsufs.2022.750199

Siddiqui, O., & Dincer, I. (2021). A comparative life cycle assessment of clean aviation fuels. *Energy*, *234*, 121126–121126. https://doi.org/10.1016/j.energy.2021.121126

Sim, S., Barry, M., Clift, R., & Cowell, S. J. (2007). The Relative Importance of Transport in Determining an Appropriate Sustainability Strategy for Food Sourcing. *International Journal of Life Cycle Assessment*, *12*(6), 422–431. https://doi.org/10.1065/lca2006.07.259

SkyTeam Virtual. (2023a). *KLM Royal Dutch Airlines Airbus A330-203*. https://skyteamvirtual.org/fleet/models/klm-airbus-a330-203

SkyTeam Virtual. (2023b). *KLM Royal Dutch Airlines Airbus A330-303*. https://skyteamvirtual.org/fleet/models/klm-airbus-a330-303

Smits, W. (2023). *The Aruban Food System and Healthy Food Choices* [Internship report]. Alimentá & HAS Green Academy.

Sociaal Economische Raad. (2020). *Advies Voedselzekerheid op aruba*. https://www.ser.aw/pages/voedselzekerheid-op-aruba-nov-2020/

Somers, E. (2012). *The Knowledge Zone on Curaçao: The potential of a creative economy for the sustainable development of a small island developing state* [Master thesis, Wageningen University & Research]. https://edepot.wur.nl/222522

Springer Nature. (2025). *The International Journal of Life Cycle Assessment: Volumes and issues*. https://link.springer.com/journal/11367/volumes-and-issues

Springmann, M., Clark, M., Mason-D’Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., … Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0

Statistics Netherlands. (2019). *Population counter*. https://www.cbs.nl/en-gb/visualisations/dashboard-population/population-counter

Statistics Netherlands. (2021). *How do we use our land?* https://longreads.cbs.nl/the-netherlands-in-numbers-2021/how-do-we-use-our-land/

Stein, A. J., & Santini, F. (2022). The sustainability of "local" food: A review for policy-makers. *Review of Agricultural, Food and Environmental Studies*, *103*, 77–89. https://doi.org/10.1007/s41130-021-00148-w

Stelten, R., & Antczak, K. A. (2023). Life at the Salty Edge of Empire: The Maritime Cultural Landscape at the Orange Saltpan on Bonaire, 1821–1960. *International Journal of Historical Archaeology*, *27*(2), 543–573. https://doi.org/10.1007/s10761-022-00660-9

Steward, R., Chopin, P., & Verburg, P. H. (2024). Supporting spatial planning with a novel method based on participatory Bayesian networks: An application in Curaçao. *Environmental Science and Policy*, *156*(103733). https://doi.org/10.1016/j.envsci.2024.103733

Stoessel, F., Juraske, R., Pfister, S., & Hellweg, S. (2012). Life cycle inventory and carbon and water foodprint of fruits and vegetables: Application to a swiss retailer. *Environmental Science and Technology*, *46*(6), 3253–3262. https://doi.org/10.1021/es2030577

Sun, W., Shao, M., Granier, C., Liu, Y., Ye, C. S., & Zheng, J. Y. (2018). Long-Term Trends of Anthropogenic SO2, NOx, CO, and NMVOCs Emissions in China. *Earth's Future*, *6*(8), 1112–1133. https://doi.org/10.1029/2018EF000822

Szabó, Z. (2025). *Kamerbrief over economische ontwikkeling en zelfredzaamheid Caribische delen van het Koninkrijk*. https://www.rijksoverheid.nl/documenten/kamerstukken/2025/03/10/kamerbrief-tk-economische-ontwikkeling-en-zelfredzaamheid-caribische-delen-van-het-koninkrijk

Takacs, B., Stegemann, J. A., Kalea, A. Z., & Borrion, A. (2022). Comparison of environmental impacts of individual meals—Does it really make a difference to choose plant-based meals instead of meat-based ones? *Journal of Cleaner Production*, *379*. https://doi.org/10.1016/j.jclepro.2022.134782

Tchonkouang, R. D., Onyeaka, H., & Nkoutchou, H. (2024). Assessing the vulnerability of food supply chains to climate change-induced disruptions. *Science of the Total Environment*, *920*. https://doi.org/10.1016/j.scitotenv.2024.171047

The Daily Herald. (2023). *Venezuela boats arrive in Aruba with fresh produce*. https://www.thedailyherald.sx/islands/venezuela-boats-arrive-in-aruba-with-fresh-produce

The World Bank. (2021). *Land area (sq. Km)—Aruba*. https://data.worldbank.org/indicator/AG.LND.TOTL.K2?locations=AW

Thévenot, A., Aubin, J., Tillard, E., & Vayssières, J. (2013). Accounting for farm diversity in Life Cycle Assessment studies—The case of poultry production in a tropical island. *Journal of Cleaner Production*, *57*, 280–292. https://doi.org/10.1016/j.jclepro.2013.05.027

Trade Map. (2025). *List of supplying markets for a product imported by Aruba. Product: 0901 Coffee*. https://www.trademap.org

TransportPolicy.net. (2018a). *Peru: Heavy-duty: Emissions*. https://www.transportpolicy.net/standard/peru-heavy-duty-emissions/

TransportPolicy.net. (2018b). *Thailand: Heavy-duty: Emissions*. https://www.transportpolicy.net/standard/thailand-heavy-duty-emissions/

TransportPolicy.net. (2018c). *US: Heavy-duty: Emissions*. https://www.transportpolicy.net/standard/us-heavy-duty-emissions/

Travel, A., Nys, Y., & Bain, M. (2011). Effect of hen age, moult, laying environment and egg storage on egg quality. In Y. Nys, M. Bain, & F. Van Immerseel (Eds), *Improving the Safety and Quality of Eggs and Egg Products: Volume 2* (pp. 300–329). Woodhead Publishing.

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., Levac, D., Ng, C., Sharpe, J. P., Wilson, K., Kenny, M., Warren, R., Wilson, C., Stelfox, H. T., & Straus, S. E. (2016). A scoping review on the conduct and reporting of scoping reviews. *BMC Medical Research Methodology*, *16*(1), 1–10. https://doi.org/10.1186/s12874-016-0116-4

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., … Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, *169*(7), 467–473. https://doi.org/10.7326/M18-0850

TwynstraGudde. (2024). *Rapport NMBP 2020 2030 Lerende evaluatie fase 1*. https://www.tweedekamer.nl/kamerstukken/detail?did=2025D32943&id=2025Z14411&utm

UNEP. (2016). *Food Systems and Natural Resources. A Report of the Working Group on Food Systems of the International Resource Panel* (Nos 978-92-807-3560–4; pp. 164–164). https://www.unep.org/resources/report/food-systems-and-natural-resources

United Nations. (1992). *Agenda 21*. https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf

United Nations. (1994). *Report of the Global Conference on the Sustainable Development of Small Island Developing States* (A/CONF.167/9). https://doi.org/10.1016/0964-5691(94)90039-6

United Nations. (2005). *Mauritius Strategy for the Further Implementation of the Programme of Action for the Sustainable Development of Small Island Developing States*. https://unctad.org/system/files/official-document/a60d401_en.pdf

United Nations. (2014). *SIDS Accelerated Modalities of Action (SAMOA) Pathway*. https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/samoa_pathway.pdf

United Nations. (2024). *The Antigua and Barbuda Agenda for SIDS (ABAS) – a Renewed Declaration for Resilient Prosperity*. https://sdgs.un.org/documents/outcome-document-antigua-and-barbuda-agenda-sids-abas-renewed-declaration-resilient

United Nations. (2026). *List of SIDS*. https://www.un.org/ohrlls/content/list-sids

United Nations Environment Programme. (2024). *Emissions Gap Report 2024: No More Hot Air … Please! With a Massive Gap Between Rhetoric and Reality, Countries Draft New Climate Commitments*. United Nations Environment Programme. https://doi.org/10.59117/20.500.11822/46404

van Berkum, S., Dengerink, J., & Ruben, R. (2018). *The food systems approach: Sustainable solutions for a sufficient supply of healthy food* (Memorandum 2018-064, pp. 32–32). https://edepot.wur.nl/451505

van de Velde, S. (2022). *Implementing community urban agriculture in Bonaire* [Master thesis, Wageningen University & Research and Delft University of Technology]. https://edepot.wur.nl/633740

van de Velde, S. (2023). *Implementing community urban agriculture in Bonaire* [Conference Presentation]. Dutch Caribbean Research Week.

van den Dungen, E. (2025). *Veldonderzoek in het kader van vergroten voedselzekerheid op Aruba, Curaçao en Sint Maarten: De visie van voedselproducenten over belemmeringen en kansen omtrent* *voedselproductie* (Versienummer 1.0). https://www.unitedfarmers.aw/wp-content/uploads/2025/03/2Rapport_Veldonderzoek-Voedselzekerheid-Aruba-Curacao-Sint-Maarten_27022025.pdf

van den Heuvel, G. (2017). Bonaire kan 40 procent groenten zelf produceren. *Caribisch Netwerk*. https://caribischnetwerk.ntr.nl/2017/11/18/bonaire-kan-40-procent-groenten-zelf-produceren/

van der Geest, M., & Slijkerman, D. (2019). *Nexus interventions for small tropical islands: Case study Bonaire. Food from the Land*. Wageningen University & Research. https://edepot.wur.nl/471565

van der Loo, K. (2022). 'If the Ship Stops Sailing': How can food sovereignty in Aruba be protected in public policy and developed as a notion in international human rights law? In *UAUCU Student Research Exchange 2022*. University of Aruba and University College Utrecht. https://hdl.handle.net/20.500.14473/1061

van Dooren, C., Loken, B., Lang, T., Meltzer, H. M., Halevy, S., Neven, L., Rubens, K., Seves-Santman, M., & Trolle, E. (2024). The planet on our plates: Approaches to incorporate environmental sustainability within food-based dietary guidelines. *Frontiers in Nutrition*, *11*. https://doi.org/10.3389/fnut.2024.1223814

van Geelen, T. L. T. (2020). *Food Supply Chain & Logistics – Bonaire, Sint Eustatius and Saba*. Netherlands Enterprise Agency and Wageningen University & Research.

van Kol, H. H. (1901). *Een Noodlijdende Kolonie*. https://archive.org/details/BNADIGKOSTBARE0097/mode/2up

Van Opstal, L. (2023). *Consumer preferences for salmon and carbon footprint trade-offs: Insights from Aruba* [Master thesis]. KU Leuven.

van Veghel, A. S. (2021). *Assessing the environmental impact of food systems* (University of Aruba & the Metabolism of Islands, Organizers) [Conference Presentation]. Sustainable Island Futures II. https://hdl.handle.net/20.500.14473/1333

van Veghel, A. S. (2022). *Aruba (Atlantic Ocean)* (B. Flipo, M. Vigne, V. Kleinpeter, & J. Vayssières, Eds; pp. 34–34). CIRAD. https://hdl.handle.net/20.500.14473/1037

van Veghel, A. S. (2024). *Research on food in the Dutch Caribbean* [Keynote]. Dutch Caribbean Research Week.

van Veghel, A. S., Bleukx, K., Janssens, D., van den Bergh, J., van Krunkelsven, E., Honeth, M., & Geeraerd, A. (2021). *Insight into the environmental impact of the food basket of an island: Case study of Aruba. Challenges and solutions in moving from an exploratory analysis towards a more detailed analysis.* (ISEKI-Food Association, Organizer) [Conference Presentation].

van Veghel, A. S., Michiels, F., & Geeraerd, A. (2022). Exploring the carbon footprint of different vegetable choices in Aruba, a food import dependent island. *13th International Conference on Life Cycle Assessment of Food 2022 (LCA Foods 2022) On "The Role of Emerging Economies in Global Food Security"*. https://lirias.kuleuven.be/retrieve/693398

van Veghel, A. S., Perez, V., Sultan, S., & Pin, R. (2025). *Characteristics of research on human food and beverage supply and consumption in Aruba, Bonaire, and Curacao: A scoping review protocol*. https://osf.io/8egzc/

van Veghel, A. S., Sultan, S., & Geeraerd Ameryckx, A. (2024). The carbon footprint of vegetable imports into Aruba: A closer look at sea and air transport. *Future Foods*, *10*. https://doi.org/10.1016/j.fufo.2024.100469

Vázquez-Rowe, I., Hospido, A., Moreira, M. T., & Feijoo, G. (2012). Best practices in life cycle assessment implementation in fisheries. Improving and broadening environmental assessment for seafood production systems. *Trends in Food Science and Technology*, *28*(2), 116–131. https://doi.org/10.1016/j.tifs.2012.07.003

Velders, G. J. M., Wesseling, J., Geilenkirchen, G. P., & Ligterink, N. E. (2013). *The Euro emission standards for cars and trucks in relation to NO2 limit value exceedances in the Netherlands*. https://www.rivm.nl/publicaties/euro-emission-standards-for-cars-and-trucks-in-relation-to-no2-limit-value-exceedances

Vermeij, M. J. A., Latijnhouwers, K. R. W., Dilrosun, F., Chamberland, V. F., Dubé, C. E., Van Buurt, G., & Debrot, A. O. (2019). Historical changes (1905-present) in catch size and composition reflect altering fisheries practices on a small Caribbean island. *PLoS ONE*, *14*(6), 1–17. https://doi.org/10.1371/journal.pone.0217589

Vermeulen, P. C. M., & Van Der Lans, C. J. M. (2011). Combined heat and power (CHP) as a possible method for reduction of the CO2 footprint of organic greenhouse horticulture. *Acta Horticulturae*, *915*, 61–68. https://doi.org/10.17660/ActaHortic.2011.915.7

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, *37*, 195–222. https://doi.org/10.1146/annurev-environ-020411-130608

Verones, F., Bare, J., Bulle, C., Frischknecht, R., Hauschild, M., Hellweg, S., Henderson, A., Jolliet, O., Laurent, A., Liao, X., Lindner, J. P., Maia De Souza, D., Michelsen, O., Patouillard, L., Pfister, S., Posthuma, L., Prado, V., Ridoutt, B., Rosenbaum, R. K., ... Fantke, P. (2017). LCIA framework and cross-cutting issues guidance within the UNEP-SETAC Life Cycle Initiative. *Journal of Cleaner Production*, *161*, 957–967. https://doi.org/10.1016/j.jclepro.2017.05.206

Verstraeten, S., Griffith-Lendering, M., Pin, R., & Volksgezondheid Instituut Curaçao. (2017). *De nationale gezondheidsenquête Curaçao* (pp. 1–174). https://www.vic.cw/storage/app/media/Publicaties/Rapport NGE 2017.pdf

Verstraeten, S., Pengpid, S., Peltzer, K., & Merrick, J. (2020). *Global school-based student health survey in Curaçao*.

Verteramo Chiu, L. J., Nicholson, C. F., Gómez, M. I., & Mattson, N. S. (2024). A meta-analysis of yields and environmental performance of controlled-environment production systems for tomatoes, lettuce and strawberries. *Journal of Cleaner Production*, *469*. https://doi.org/10.1016/j.jclepro.2024.143142

Visser, B. (2021). *Samyama Permaculture Transition* (University of Aruba & the Metabolism of Islands, Organizers) [Conference Presentation]. Sustainable Island Futures II. https://hdl.handle.net/20.500.14473/1333

Visser, B., Carmona Báez, A., Echteld, E., & Mijts, E. (2024). Curaçao Food Security before and during COVID-19; evaluation of the island's food Availability, Accessibility, and Stability. In N. Faraclas, R. Severing, E. Echteld, S. Delgado, & W. Rutgers (Eds), *Southern Entanglements: Southern Epistemologies, Southern Praxes and The Languages, Literatures and Cultures of the Dutch Caribbean and Beyond* (Vol. 1, pp. 71–88). University of Curaçao/University of Puerto Rico. https://islandsinbetween.com/2023-volume-1/

VRR. (n.d.). *AKE Container LD3*. Retrieved https://vrr.aero/products/ake-container/

Willems, C. (2015). *Franchising: Preference between foreign-based fast food restaurants versus local based restaurants in Curaçao* [Bachelor thesis]. University of Curacao.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Majele Sibanda, L., ... Murray, C. J. L. (2019). Food in the Anthropocene:

The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, *393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Woodhill, J., Hasnain, S., & Griffith, A. (2020). *Farmers and food systems: What future for small-scale agriculture?* (Environmental Change Institute, University of Oxford, Oxford). https://www.eci.ox.ac.uk/sites/default/files/2022-05/Farming-food-WEB.pdf

WWF. (2020). *Living Planet Report 2020—Bending the curve of biodiversity loss* (R. E. A. Almond, M. Grooten, & T. Petersen, Eds). https://f.hubspotusercontent20.net/hubfs/4783129/LPR/PDFs/ENGLISH-FULL.pdf

WWF & Climate Focus. (n.d.). *Food Forward NDCs*. Food Forward NDCs. Retrieved 22 February 2026, from https://foodforwardndcs.panda.org/

WWF-Netherlands & Good Fish Foundation. (2020). *Analysis of the seafood supply chain on Bonaire, Saba and St. Eustatius*. https://www.goodfish.nl/app/uploads/2022/02/WWF-Caribbean-Netherlands_2019_Analysis-of-the-seafood-supply-chain-on-Bonaire-Saba-and-St.-Eustatius_FINAL.pdf

Zaneveld, J. S. (1944). *Sea fisheries of the Netherlands Antilles*.

Ziegler, F., Hornborg, S., Green, B. S., Eigaard, O. R., Farmery, A. K., Hammar, L., Hartmann, K., Molander, S., Parker, R. W. R., Skontorp Hognes, E., Vázquez-Rowe, I., & Smith, A. D. M. (2016). Expanding the concept of sustainable seafood using Life Cycle Assessment. *Fish and Fisheries*, *17*(4), 1073–1093. https://doi.org/10.1111/faf.12159

Ziegler, F., Nilsson, K., Levermann, N., Dorph, M., Lyberth, B., Jessen, A. A., & Desportes, G. (2021). Local seal or imported meat? Sustainability evaluation of food choices in greenland, based on life cycle assessment. *Foods*, *10*(6), 1–14. https://doi.org/10.3390/foods10061194

Zúñiga-Venegas, L. A., Hyland, C., Muñoz-Quezada, M. T., Quirós-Alcalá, L., Butinof, M., Buralli, R., Cardenas, A., Fernandez, R. A., Foerster, C., Gouveia, N., Jara, J. P. G., Lucero, B. A., Muñoz, M. P., Ramírez-Santana, M., Smith, A. R., Tirado, N., de Joode, B. van W., Calaf, G. M., Handal, A. J., … Mora, A. M. (2023). Health Effects of Pesticide Exposure in Latin American and the Caribbean Populations: A Scoping Review. *Environmental Health Perspectives*, *131*(8). https://doi.org/10.1289/EHP13645

PART VI

APPENDICES

STATEMENT: USE OF GENERATIVE AI

I did use generative AI assistance tools. OpenAI (GPT-5) was used to generate the image on the cover, for improving texts, and as a search engine to learn more about a particular topic. Specifically, to find additional literature for the introduction and discussion of my doctoral dissertation.

The text and images in this thesis are my own (unless otherwise specified) and generative AI has only been used in accordance with the KU Leuven guidelines and appropriate references have been added. I have reviewed and edited the content as needed and I take full responsibility for the content of the thesis.

LIST OF PUBLICATIONS

PEER-REVIEWED ACADEMIC JOURNALS

1. van Veghel, A. S., Sultan, S., & Geeraerd Ameryckx, A. (2024). The carbon footprint of vegetable imports into Aruba: A closer look at sea and air transport. *Future Foods, 10*. https://doi.org/10.1016/j.fufo.2024.100469

2. De Vlieghere*, A., van Veghel, A.S.*, Geeraerd Ameryckx, 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. *International Journal Of Life Cycle Assessment, 11*. doi: 10.1007/s11367-023-02207-4 *shared first authorship

3. Geerts, M., van Veghel, A., Zisopoulos, F.K., Van der Padt, A., Van der Goot, A.J. with Van der Goot, A.J. (2018). Exergetic comparison of three different processing routes for yellow pea (*Pisum sativum*): Functionality as a driver in sustainable process design. *Journal of Cleaner Production*, *183*, 979-987. doi: 10.1016/j.jclepro.2018.02.158

OTHER WRITTEN PUBLICATIONS

1. Flantua, E., van Veghel, A.S. (2019). *Boeren in Flevoland op zoek naar de consument* [inventarisation / online blog]. Flevo Campus. Almere, the Netherlands. https://flevocampus.nl/boeren-in-flevoland-op-zoek-naar-de-consument/

2. van Veghel, A.S. (2017). *The environmental impact of green proteins and their role in a healthy diet* [internship report]. Blonk Consultants. Gouda, the Netherlands. https://blonksustainability.nl/news/revealing-the-environmental-impact-of-plant-proteins#gsc.tab=0

INTERNATIONAL SCIENTIFIC CONFERENCES

1. van Veghel, A.S., Sultan, S., Geeraerd Ameryckx, A. (2023, October 23). *Frequently Asked Questions about lowering the environmental impact of our food consumption, for islands* [Conference presentation]. Turning the Tide: Climate Change, Social Change, and Islandness – The Second International Conference on Small Island States and Subnational Island Jurisdictions. Oranjestad, Aruba.

2. van Veghel, A.S., Michiels, F., Sultan, S., Geeraerd Ameryckx, A. (2023, May 12). *Vegetables should be qualitative, tasty, and affordable, but what about their carbon footprint?* [Conference presentation / KU Leuven seminar]. SISSTEM Symposium. Oranjestad, Aruba.

3. van Veghel, A.S., Michiels, F., Geeraerd Ameryckx, A. (2022, October 12-14). *Exploring the carbon footprint of different vegetable choices in Aruba, a food import dependent island* [Conference paper]. The Role of Emerging Economies in Global Food Security, (588-592). 13th International Conference on Life Cycle Assessment of Foods - LCA Foods 2022. Lima, Peru. ISBN: 9789972674327

4. van Veghel, A.S., Geeraerd Ameryckx, A. (2022, June 20). *Ongoing research about the environmental impact of food chains in Aruba, using life cycle assessment (LCA)* [Conference presentation]. 1st Postgraduate Conference in Island and Small States Studies. Valletta, Matla.

5. van Veghel, A.S., Couwet, E., van Hoof, S., Vanhee, Y., Tombeur, J., Geeraerd Ameryckx, A. (2022, June 13-17). *Environmental impact of Curacao's food and beverage Imports* [Poster presentation]. Dutch Caribbean Research Week 2022. Online.

6. van Veghel, A.S., Bleukx, K., Janssens, D., van den Bergh, J., van Krunkelsven, E., Honeth, M., Geeraerd, A. (2021, June 23). *Insight into the environmental impact of the food basket of an island: case study of Aruba. Challenges and solutions in moving from an exploratory analysis towards a more detailed analysis* [Conference presentation]. 6th International ISEKI-Food Conference. Sustainable Development Goals in Food Systems: Challenges and Opportunities for the Future, (Abstract No. 343). Online. doi: 10.34623/9hhy-1y83

7. van Veghel, A.S., Bleukx, K., Janssens, D., van den Bergh, J., van Krunkelsven, E., Honeth, M.E R., Geeraerd, A. (2020, December 3). *Ongoing research on the environmental impact of Aruba's food basket* [Conference presentation]. (Abstract No. 6). Sustainable Islands Futures 2021. Online. https://hdl.handle.net/20.500.14473/1332

KU LEUVEN SEMINARS

1. van Veghel, A.S. (2024, August 8). *Research proposal for quantifying the environmental impact of Aruba's food consumption, and the sensitivity of different food consumption choices* [KU Leuven seminar]. KU Leuven. Leuven, Belgium.

2. van Veghel, A.S., Michiels, F., Sultan, S., Geeraerd Ameryckx, A. (2023, May 12). *Vegetables should be qualitative, tasty, and affordable, but what about their carbon footprint?* [Conference presentation / KU Leuven seminar]. SISSTEM Symposium / KU Leuven. Oranjestad, Aruba.

PRESENTATIONS FOR THE GENERAL PUBLIC

1. van Veghel, A.S. (2025, May 27). *Why Food Should Be on the Climate Agenda* [presentation]. Caribbean Climate & Energy Conference. Willemstad, Curacao.

2. van Veghel, A.S. (2025, April 26). *Research on Food in the Dutch Caribbean* [keynote]. Dutch Caribbean Research Week 2025. Willemstad, Curacao.

3. van Veghel, A.S. (2024, April 22). *Understanding Your Menu's Carbon Footprint* [keynote]. The Global Vegan Hospitality & Tourism Online Conference. Online.

4. van Veghel, A.S. (2024, April 11). *The Environmental Impact of Aruba's Food Consumption using Life Cycle Assessment (LCA)* [presentation]. KIVI Kring Caribbean. Oranjestad, Aruba.

5. van Veghel, A.S. (2022, May 16). *Where does our food come from?* [workshop]. For: Colegio Nigel Matthew. Dutch Caribbean Research Week. San Nicolas, Aruba. https://www.youtube.com/watch?v=YAiAmRBiazM

6. van Veghel, A.S. (2022, May 12). *The future of Curacao's food consumption* [presentation]. Curacao Think Tank. Online.

7. van Veghel, A.S. (2022, April 21). *De relatie tussen voedsel en klimaatverandering* [presentation in collaboration with Cindy Eman and Yolanda Wiel from Kolektivo (Curacao)]. For: Representation of the Netherlands. Willemstad, Curacao.

8. van Veghel, A.S. (2022, March 25). *What is the carbon footprint of our food consumption?* [presentation]. For: Representation of the Netherlands. Oranjestad, Aruba.

9. van Veghel, A.S. (2022, March 10). *What is the carbon footprint of our food consumption?* [presentation]. For: Kiwani's Aruba. Oranjestad, Aruba.

10. van Veghel, A.S. (2022, February 7). *The carbon footprint of our food consumption* [presentation]. Climate Change Symposium. Oranjestad, Aruba.

11. van Veghel, A.S. (2022, January 11). *The science behind sustainable food systems* [keynote]. SDGCuracao2030. Online.

12. Balentien, G. Kolk, C., van Veghel, A.S. (2020, June 25). *Pastechi: van graan tot snèk* [presentation]. Natuurhistorisch Museum Curaçao. Online.

13. van Veghel, A.S. (2020, June 4). *Are we programmed to make unsustainable food choices?* [presentation]. Impact by Sustainable Programming, conference organized by Innovation Ç (Curacao). Online.

14. Daal, A, van Veghel, A.S. (2020, May). *Kosecha Futuro* [presentation]. Curacao Ministry of Health, Environment, and Nature. Online.

ABOUT THE AUTHOR

A.S. (Amber) van Veghel was born in Curaçao in 1994 at 359 parts per million[2]. Her family roots extend across Curaçao, the Netherlands, and Bonaire. She works across the Caribbean as a publishing researcher, project manager, and entrepreneur, addressing complex systemic challenges and translating scientific insights into accessible knowledge.

From an early age, she developed a curiosity about the origins and production of food, which led her to obtain both a Bachelor's and Master's degree in Food Technology from Wageningen University & Research. What began with questions about the crispiness of French fries and the viscosity of peanut butter evolved into a broader interest in the environmental and social impact of food systems.

After three years of professional experience in the Netherlands in the field of food and sustainability, she returned to Curaçao. She subsequently began her PhD in the SISSTEM program at the University of Aruba as part of the *Sustainability in the Agri-Food Chain Group* at KU Leuven. Since 2022, she has been an organizing member of the *Sustainable Diets Journal Club*, an international online platform for early-career scholars studying the environmental and social impact of dietary patterns and food systems. Van Veghel is particularly skilled in translating complex topics into accessible and actionable insights. She regularly delivers lectures, workshops, and conference presentations, engaging audiences ranging from secondary school students to policymakers and academic communities across and beyond the Caribbean.

Her publications and ongoing projects can be followed via ResearchGate and LinkedIN.

[2] In *Breaking Boundaries: The Science of Our Planet*, Johan Röckstrom and Owen Gaffney introduce themselves by referencing the annual mean atmospheric carbon dioxide concentration in their birth years. This concentration was 316 ppm, 359 ppm and 427 ppm in 1959 (first measurement), 1994, and 2025, respectively (Lan & Keeling, 2026).