Jamaica's Climate Change Research Agenda

2020-2030

Solutions for the Inclusive Green Development
Soluciones para el Desarrollo Verde Inclusivo

CLIMATE TECHNOLOGY CENTRE & NETWORK

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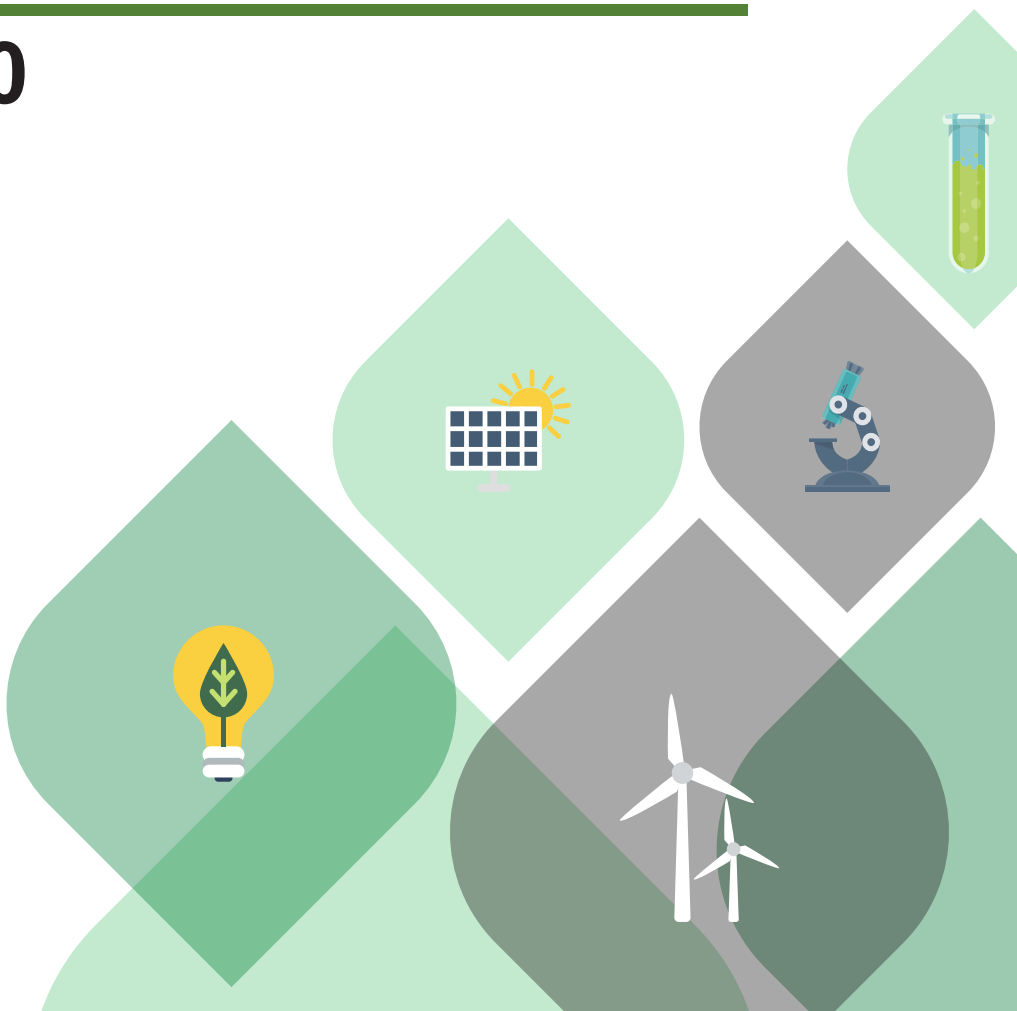

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Acronyms

ACDI/VOCA	Agricultural Cooperative Development International/Volunteers in Overseas Cooperative Assistance
ADO	Automotive Diesel Oil
AWS	Automatic Weather Station
BESS	Battery Energy Storage System
BIS	Beneficiary Identification System
CARICOM	Caribbean Community
CC	Climate Change
CDB	Caribbean Development Bank
CFDP	Caribbean Fisheries Development Project
CIF	Climate Investment Funds
CPT	Climate Predictability Tool
CRED	Centre for Research on the Epidemiology of Disasters
CSGM	Climate Studies Group Mona
CTCN	Climate Technology Centre and Network
DRR	Disaster Risk Reduction
EECP	Energy Efficiency and Conservation Programme
EFW	Energy From Waste
EMEP	Energy Management and Efficiency Programme
FAO	Food and Agriculture Organization
FLW	Food Loss and Waste
GDP	Gross Domestic Product
GNP	Gross National Product
GHG	Greenhouse Gas
HEC-HMS	Hydrologic Engineering Center–Hydrologic Modeling System
IAEA	International Atomic Energy Agency
ICCAT	International Commission for Conservation of Atlantic Tunas
ICDIMP	Improving Climate Data and Information Management Project
ICENS	International Centre for Environmental and Nuclear Sciences
ICT	Information and Communication Technology
IDB	Inter-American Development Bank
IMTA	Integrated Multitrophic Aquaculture
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRI	International Research Institute for Climate and Society
IWM	Integrated Waste Management
JACRA	Jamaica Agricultural Commodities Regulatory Authority
JaREEACH	Jamaica Rural Economy and Ecosystems Adapting to Climate Change
JPS	Jamaica Public Service
JSIF	Jamaica Social Investment Fund
KSA	Kingston and St. Andrew
KMA	Kingston Metropolitan Area
LAC	Latin America and the Caribbean
LULUCF	Land Use, Land-Use Change and Forestry
MICAF	Ministry of Industry, Commerce, Agriculture, and Fisheries
MSET	Ministry of Science, Energy and Technology
MSW	Municipal Solid Waste

NCST	National Commission on Science and Technology
NDC	Nationally Determined Contribution
NEPA	National Environment and Planning Agency
NIC	National Irrigation Commission
NGO	Non-Governmental Organisation
NSWMA	National Solid Waste Management Authority
NWC	National Water Commission
ODPEM	Office of Disaster Preparedness and Emergency Management
OUR	Office of Utilities Regulation
PIOJ	Planning Institute of Jamaica
PPCR	Pilot Programme for Climate Resilience
PPP	Public-Private Partnership
PSW	Particle Swarm Optimisation
R&TD	Research and Technology Development
RADA	Rural Agricultural Development Authority
REDI	Rural Economic Development Initiative
SDG	Sustainable Development Goal
SEI	Stockholm Environment Institute
SIDS	Small Island Developing State
SIRI	Sugar Industry Research Institute
SOM	Soil Organic Matter
SPI	Standardised Precipitation Index
SRC	Scientific Research Council
STATIN	Statistical Institute of Jamaica
ST&I	Science, Technology and Innovation
STEM	Science, Technology, Engineering and Mathematics
STP	Sewage Treatment Plants
SWAT	Soil and Water Assessment Tool
TMR	Total Mixed Ration
TNA	Technology Needs Assessment
ULSD	Ultra-Low Sulphur Diesel
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USAID I Jamaica	United States Agency for International Development Mission in Jamaica
UWI	The University of West Indies
WASH	Water, Sanitation and Hygiene
WB	World Bank
WEAP	Water Evaluation and Planning
WMU	Watershed Management Unit
WRA	Water Resources Authority

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Executive summary

Climate change is already occurring across Jamaica, impacting the social, economic, and environmental dimensions of most sectors and the livelihoods that depend on them. The island therefore needs to implement decisive mitigation strategies to reduce greenhouse gas emissions and apply innovative adaptive measures in all sectors. Addressing the problems that arise from climate variability and change requires a research agenda that consolidates, streamlines, and expands on previous work, highlights knowledge gaps, and encourages new knowledge and innovations. Users' engagement and public-private collaboration are critical to ensuring the adoption of sustainable practices.

With the support of the Climate Technology Centre and Network (CTCN), the first phase of defining a road map for targeted research in Jamaica began in September 2020. The process focused on research and technological development activities that can contribute to implementing the enhanced NDC for mitigation and adaptation submitted by Jamaica to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat in June 2020. During the development process, an effort was made to identify and analyse existing capacities in universities, research centres, and the private sector, whose lines of work support climate change priorities and the development of technological capacities in productive activities.

This document presents an agenda for research and technology development (RT&D), the result of a co-creation process with academia, R&TD centres, and the private sector, to support climate change targets in the key sectors identified for the first phase: agriculture and fisheries, water, human settlement and infrastructure, waste, and energy. The sectors were prioritised using a multicriteria analysis that took account of the need for new knowledge to address climate change impact-related issues, as well as the importance of each sector in terms of economic impact, climate, environmental, and social impact. Figure 1 presents the research themes identified by sector. The research agenda is explained in nine chapters. Chapters 3 to 8 comprise an analysis of each sector and present proposed research and development priorities, organised by theme, each associated with concreted expected outcomes. In chapter 9, a discussion regarding the enabling factors for successful implementation is presented.

The research will generate new knowledge to orient investments in multiscalar mitigation and adaptation strategies for various subsectors. Successful implementation of the agenda will improve decision making in the agriculture and fisheries, water, energy, human settlement and infrastructure, and waste sectors to address climate change, rural poverty, and food security, using research to identify strategies that maximise social benefits. Adequate financing of this research and innovation agenda and strengthening human resources will be critical to success.

Research themes by sector

1

Theme 1: Mitigating risk, hazard and climate change
Theme 2: Ensuring climate change resilience and adaptation
Theme 3: Developing synergies and reducing trade-offs between food supply, biodiversity and ecosystem services

Agriculture and fisheries

2

Theme 1: Climate-proofing water and sanitation infrastructure for health, livelihoods and economic development
Theme 2: Water resources management, governance and the environment

Water

3

Theme 1: Climate vulnerability modelling for energy systems
Theme 2: Energy generation (renewable sources)
Theme 3: Energy efficiency

Energy

4

Theme 1: Enhancing the adaptive capacity of the sector to climate change effects.
Theme 2: Contributing to the mitigation of climate change impact

Human Settlement and Infrastructure

5

Theme 1: Reduction of emissions from the waste sector

Waste

Figure 1. *Research themes by sector*

Chapter 1

Introduction

Introduction

Climate change is already occurring across Jamaica, impacting the social, economic, and environmental dimensions of many sectors and the livelihoods that depend on them. The island therefore needs to implement decisive mitigation strategies to reduce greenhouse gas emissions and adopt innovative adaptive measures in all sectors. Addressing the problems that arise from climate variability and change requires an agenda that is specific to Jamaica, strengthens research capacities, and establishes new research priorities. A research agenda is needed to consolidate, streamline and expand on previous work, highlight knowledge gaps, and encourage new knowledge and innovations. The complexities of economic systems and their role in Greenhouse Gas (GHG) emissions, the vulnerability of rural livelihoods, the site-specificity of climatic impacts, as well as political and socioeconomic conditions, mean that a broad range of empirical research themes and methodologies within the Jamaican context is required to achieve development goals.

Even though there is broad agreement on the need for strengthening research for development, there remains a vague understanding of how the identified knowledge gaps should be filled. Hence, focusing on the methods for implementing this research agenda within the various subsectors is also vital for tailoring intervention programmes and plans to facilitate long-term development. It is also imperative to consolidate research and technological development (R&TD) capacities and thereby guarantee an adequate transfer and assimilation of the acquired technology to assess the potential impacts of climate change and develop adaptation strategies.

With the support of the Climate Technology Centre and Network (CTCN), the first phase of defining a road map for targeted research in Jamaica began in September 2020. The process focused on research and technological development activities that can contribute to implementing the enhanced NDC submitted by Jamaica to the UNFCCC secretariat in June 2020. During the process, an effort was made to identify and analyse existing capabilities in universities, research centres, and the private sector, whose lines of work are related to climate change and the interventions needed to promote the development of technological capacities in productive activities. The first stage of defining research priorities focused on the following sectors: agriculture and fisheries, water, energy, human settlement and infrastructure, and waste management.

This agenda presents multidisciplinary R&TD to address climate change adaptation and mitigation targets, prioritised in collaboration with academia, research centres, and the private sector. It builds on existing policy and planning frameworks, including Jamaica's NDC and Vision 2030 Jamaica – National Development Plan. Key stakeholders, including ministries in charge of key sectors, associated organisations, universities and research organisations, the private sector, and gender focal

points, have agreed on this R&TD agenda that incorporates strategic, long-term, participatory, and transformational measures across key activities that drive climate-resilient and low carbon growth in Jamaica.

The successful implementation of this research agenda will result in:

- New knowledge for agriculture and fisheries, water, energy, human settlement and infrastructure, and waste sectors.
- Economic benefits through investment in multiscalar mitigation and adaptation strategies for various subsectors.
- Improved decision making that addresses climate change, rural poverty, and food security, using research to identify strategies that maximise social benefits.
- Improved awareness of the various segments of the sector, and their associated activities, which can be strategically targeted for emission reduction and adaptation actions.
- Improved awareness of the relationship between the food system and the environment.
- Strengthening of local, national, regional, and international links through stakeholder partnerships.
- Contributing to fulfil international commitment such as the Paris Agreement, the Sustainable Development Goals (SDG) 2030, and Sendai Framework for Disaster Risk Reduction (DRR).

Chapter 2

Development of the Climate Change Research Agenda

2. Development of the Climate Change Research Agenda

Development of the research agenda began in September 2020 as a co-creation process, with stakeholders from public, private, and civil society organisations participating in the initial stages. Problems affecting each sector and specific research needed to overcome limitations were identified.

Figure 2. *Stages of the co-creation process*

Three inception workshops were held with the private sector, government and academia, and civil society stakeholders, encouraging a shared conceptualisation of the research agenda. Figure 3 shows the word cloud produced with the keywords mentioned by the participants. Keywords such as funding, policy engagement and collaboration were the most frequently mentioned, highlighting these as pillars of the research agenda.

Figure 3. *Word cloud generated from keywords identified by stakeholders from public, private, and civil society sectors*

Prioritisation process

To develop the R&TD agenda, the economic sectors in which research is essential for maximising positive environmental, economic, and social impacts needed to be defined. To this end, the team designed a multicriteria analysis to prioritise the sectors through a participatory process and participants were asked to rank each sector using the chosen criteria. The complete set of sectors was presented in three workshops in which the participants:

- Validated the list of identified sectors.
- Assigned weight to each criterion.
- Within each criterion, prioritised those in which research is essential for maximising positive environmental, economic, and social impacts.

The criteria used to rank the sectors were the following:

- **The need for new knowledge to address climate change impact-related issues:** Options: low knowledge need (well-studied), medium knowledge need, high need for new knowledge to solve problems.
- **Economic impact:** further research in this category within each sector may improve the country's economy (e.g. due to the sector's importance to GDP, or the labour force involved in the industry). Options: low economic impact, medium economic impact, high economic impact.
- **Climate impact:** research in this category within each sector may contribute to a decrease in GHG emissions and improved adaptation. Options: low climate impact, medium climate impact, high climate impact.
- **Environmental impact:** research in this category within each sector may contribute to protecting the environment and biodiversity. Options: low environmental impact, medium environmental impact, high environmental impact.
- **Social impact:** research in this category within each sector may contribute to poverty reduction, reduce inequity and improve health. Options: Low social impact, medium social impact, high social impact.

Table 1. *Weight given to each criterion*

Criteria	Weight
The requirement for new knowledge	15
Economic impact	22
Climate impact	19
Environmental impact	21
Social impact	22
Total	100

Results of the participatory prioritisation process show that human settlements and infrastructure, water, agriculture (and fisheries), energy, and waste are the five sectors with the highest score (Table 2).

Table 2. *Results of the participatory prioritisation process*

Sector	Requirement of new knowledge	Economic impact	Climate impact	Environmental impact	Social impact	Total weighted
Human settlements and infrastructure	2.45	2.57	2.47	2.64	2.70	**2.58**
Water	2.30	2.49	2.38	2.66	2.74	**2.53**
Agriculture	2.23	2.66	2.45	2.60	2.51	**2.51**
Energy	2.23	2.62	2.45	2.64	2.32	**2.46**
Waste	2.47	2.28	2.40	2.66	2.51	**2.46**
Human health	2.45	2.66	2.15	2.30	2.60	2.44
Coastal and marine resources	2.30	2.34	2.28	2.55	2.36	2.37
Transportation	2.11	2.28	2.45	2.47	2.32	2.33
Tourism	2.00	2.60	2.28	2.47	2.21	2.33
Forestry, terrestrial resources,and biodi-versity	2.23	2.19	2.45	2.68	2.09	2.32
Manufacturing	2.19	2.38	2.13	2.26	2.40	2.28
Fisheries	2.13	2.17	2.00	2.45	2.36	2.23
Mining & Quarrying	1.96	2.15	2.15	2.51	2.06	2.18
Criterion weight	15	22	19	21	22	

The need for a research agenda

Until now, Jamaica has not had a research and development agenda that tackles climate change and other pertinent areas at the national level. Public R&D agencies such as the Scientific Research Council (SRC), the International Centre for Environmental and Nuclear Sciences (ICENS), and the National Commission on Science and Technology (NCST) generally design their own research agenda independent of each other, which often leads to fragmentation and, in some cases, overlaps. Consequently, integrated progress on climate adaptation and mitigation targets may be hindered. Furthermore, bilateral interviews revealed that stakeholders generally consider these high-level research-oriented commitments toward reducing GHG emissions and tackling climate change impacts futile without any concrete action plan. Hence, there has been a call for a comprehensive research and development agenda that sets priorities, assigns agencies for its implementation, and promotes integration and synergy among stakeholders for proactive actions for climate change adaptation and mitigation.

The effective implementation of the research agenda requires an enabling environment that facilitates financing mechanisms, the translation of research into policy and development plans, the equitable access and dissemination of research results, and avenues for the efficient uptake and transfer of technology. A governance strategy involving stakeholders' cooperation and collaboration is also required, including public and private agencies, financial institutions, NGOs, research bodies, and community-based organisations. Whether operating directly or indirectly, the partnership of stakeholders is integral.

Structure of the research agenda

The research agenda is explained in nine chapters. Chapters 3 to 8 comprise an analysis of each sector and present proposed research and development priorities, organised by theme, each associated with concreted expected outcomes (Figure 4). In chapter 9, a discussion regarding the enabling factors for successful implementation is presented.

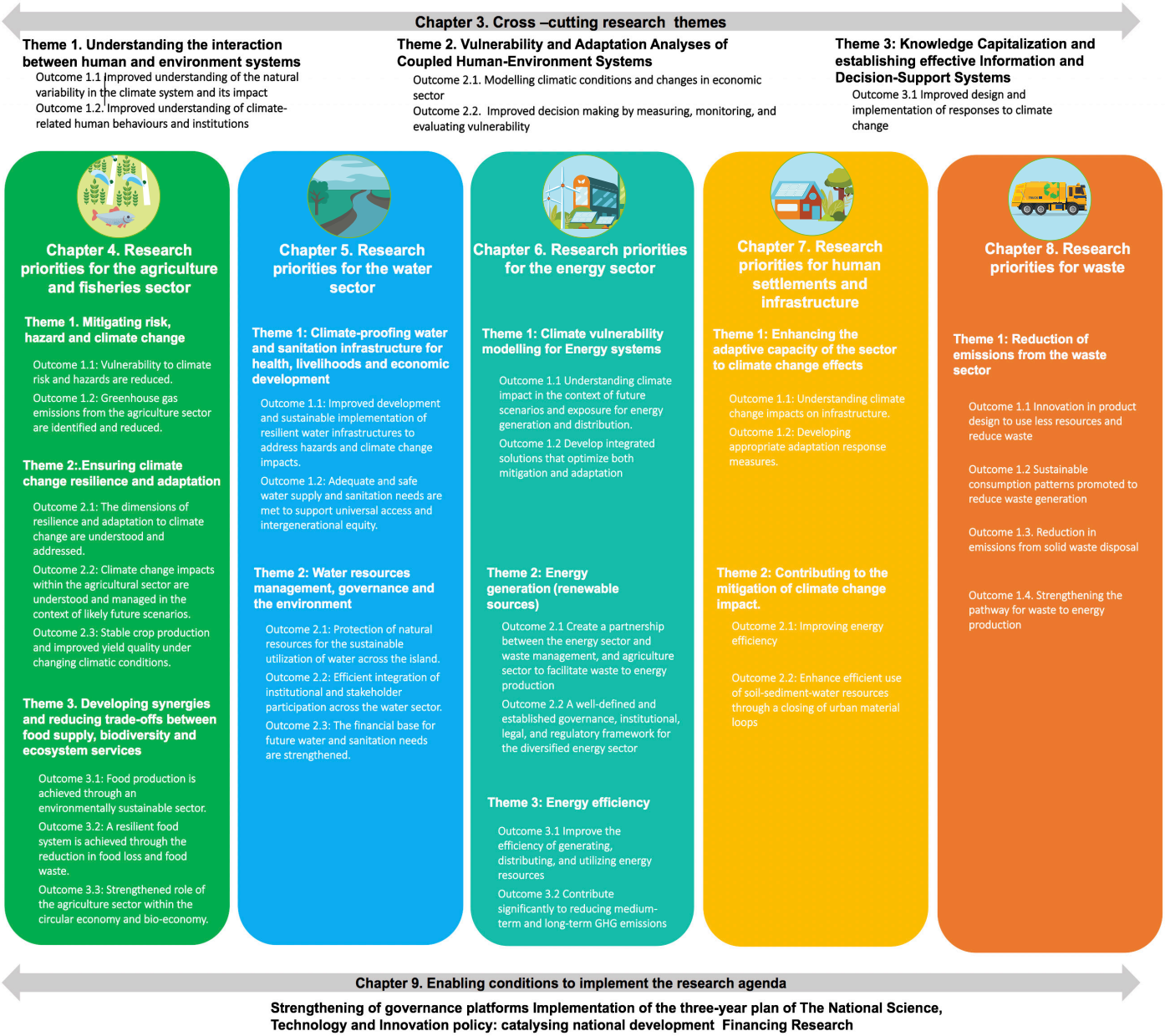

Figure 4. *Summary of themes by sector*

Chapter 3

Cross-cutting research themes

Theme 1. Understanding the interaction between human and environment systems

- **Outcome 1.1** Improved understanding of natural variability in the climate system and its impact
- **Outcome 1.2** Improved understanding of climate-related human behaviours and institutions

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Theme 2. Vulnerability and adaptation analyses of coupled human-environment Systems

- **Outcome 2.1** Modelling climatic conditions and changes in economic sector
- **Outcome 2.2** Improved decision making by measuring, monitoring, and evaluating risk of climate change

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Theme 3. Knowledge capitalisation and establishment of effective information and decision support systems

- **Outcome 3.1** Improved design and implementation of responses to climate change

3. Cross-cutting Research Themes

Several cross-cutting research themes are integral to adapting to and mitigating climate change. These themes highlight areas where science may significantly impact, fill research gaps and offer approaches to accelerate adaptation and mitigation research. This section presents these central themes commonly identified and highlighted by stakeholders and in national development documents.

Theme 1. Understanding the interaction between human and environmental systems

Understanding climate change and its effects on human and environmental systems would benefit from new information and analysis of the Earth system, including the atmosphere, land surface, cryosphere, oceans, and their interaction. In this regard, research is needed based on expanded experimental and modelling capacity to better understand climate forcing, feedback, responses, and thresholds in the Earth system.

Outcome 1.1 Improved understanding of the natural variability in the climate system and its impact

Improving data gathering mechanisms to capture microclimatic data to better inform decision making is fundamental. Stakeholders have admitted to either guessing climate data or using averages to advise individuals at the grassroots level. Microclimates characterise the island due to its topography. Consequently, varying microclimates and topographic challenges affect energy systems, water infrastructure, settlements, and waste management operations. There is a significant need for accurate and site-specific climate and weather data for different production areas and potential development sites, especially for rural areas.

RT&D activities to address knowledge gaps

- Develop a detailed outlook for each sector to identify current and future impacts due to climate variability and change.
- Improve data collection mechanisms to capture climate variability and change to inform stakeholders within various sectors better. Expand regular observations of climate variables and monitor properties in the atmosphere, oceans, land, and cryosphere, as well as related biological, ecological, and socioeconomic processes, to have a comprehensive climate observing system.
- Enhance methodologies and research on monitoring GHG emissions and carbon sequestration across sectors.

Outcome 1.2. Improved understanding of climate-related human behaviours and institutions

As the National Research Council (2010) highlights, analysing human and social systems is crucial for responding to climate change. Understanding the dynamics of the human and social system strengthens the capabilities of governments to provide sound solutions to climate-related problems, for instance, prioritisation of investments to increase resilience based on particularities of the coastal communities facing sea-level rise. Additionally, the analysis provides inputs regarding the alignment of national commitments (e.g. NDCs) with development projects funded by the government and international organisations. An in-depth understanding of human behaviour and the role of institutions and organisations is therefore central to effective policies. The research activities concerning the intersection of human and social systems that have been prioritised by the public, private and civil society and will contribute to improving decision-making processes are outlined below.

RT&D activities to address knowledge gaps

- Foster training and capacity building to develop local expertise and knowledge on climate-related human behaviours.
- Improve understanding of stakeholders and responsibilities that are critical for decision making and nation building. This will provide vital elements for the establishment of a public education programme.
- Conduct research on the policy support provided to various subsectors concerning support received and GHG emissions intensity.
- Explore opportunities to develop more significant synergies between sectors with a view to increasing their participation within the circular economy.
- Gather further knowledge about decision making across multiple levels of governance and communities and identify critical conditions for effective action plans, as well as barriers to implementation.

Theme 2: Vulnerability and adaptation analyses of coupled human-environment systems

Achieving a balance between human and environmental systems favours positive outcomes for any sustainable development agenda. Identifying environmental or climate vulnerabilities without meaningful data means that any proposed or implemented solution can be quickly derailed or even have an adverse effect when that solution meets societal behaviours and norms. Human capital skills, knowledge, ideas, and behaviours can drive economic growth. Therefore, adaptation assessments and analysis should incorporate human and environmental factors in agriculture and fisheries, waste, energy, water, human settlements and infrastructure, and vulnerabilities.

Outcome 2.1. Modelling climatic conditions and changes in economic sectors

Rainfall and temperature datasets are accessible from the Meteorological Service of Jamaica. Nevertheless, recent consultations with their climate science experts evidenced gaps in their climate datasets and the need for increased meteorological station coverage across Jamaica. Stakeholders who contributed to the Third National Communication of Jamaica to the UNFCCC 2018 also acknowledged the need for more specific climate information for agriculture (e.g. agricultural drought information detailed for particular areas being included in weather reports rather than vague evaluations of general rainfall distribution across the island) (Ministry of Economic Growth & Job Creation, Climate Change Division et al. 2018). Improvements in agrometeorological stations and comprehensive datasets to better guide operations can help integrate key characteristics into modelling scenarios, which leads to further information for improved decision making at the local and national levels (e.g. the suitability of crops in different areas under changing climatic patterns).

Not all economic sectors will experience adverse effects. The situation will likely see positive and negative impacts in the same sector. For example, hydropower may decrease due to a drier climate while wind energy may increase productivity due to higher wind speeds, or beekeepers in the parish of Portland – a characteristically wet area – may experience drier conditions that would positively impact their production. Therefore, it is necessary to capture comprehensive data on the various microclimatic zones across the island and observe their patterns and influence on multiple sectors.

RT&D activities to address knowledge gaps

- Continue efforts to develop and strengthen local-level projections of climate data to address locally specific vulnerabilities.
- Enhance strategies and plans to guard against social, economic, and infrastructural losses from climatic hazards across sectors.
- Assess whether and how water allocation methods will change under a new climate regime, and whether there will be challenges to equity within the water sector.
- Improve the communication of projections and climate data to key stakeholders.

Outcome 2.2. Improved decision making by measuring, monitoring, and evaluating climate change risk

As Jamaica moves toward identifying and measuring the risk of climate change, it is critical to have monitoring protocols and tools in place. It is not enough to measure a sector's exposure to climatic and human impacts; that sector must be monitored to determine if implemented actions have improved or increased the previously identified vulnerability. More importantly, monitoring also helps

determine if the solution to one impact has created other situations of concern. Through this process of measuring, monitoring, and evaluating new and existing vulnerabilities, decision-making will have improved long-term outcomes.

RT&D activities to address knowledge gaps

- Enhance multiscalar mapping and research on climate-related risk across multiple priority sectors, including agriculture and fisheries, energy, water, waste, human settlement and infrastructure.
- Enhance monitoring methodologies of existing hazard mapping approaches within sectors to improve adaptation strategies and recovery plans.
- Enhance research strategies that quantify the environmental cost/benefits of maintaining and implementing various land management practices across sectors.
- Continue multidisciplinary efforts to develop more comprehensive scenarios for the drivers of climate change, socioeconomic vulnerabilities, and adaptive capacities and improve decision-making tools under uncertainty and complexity. The development of more informative scenarios contributes to a better understanding of the dynamics of coupled human-environment systems and assesses the potential effect of policy choices and mitigation and adaptation strategies.
- Enhance evaluation methodologies to examine the effectiveness of implemented adaptation strategies, especially when initiatives involve multiple components or several stakeholders.

Theme 3: Knowledge capitalisation and establishment of effective information and decision support systems

Currently, research within sectors has been characterised as fragmented. Several stakeholders mentioned the need for a national database to house a detailed inventory of research from state agencies, R&TD organisations, universities, and NGOs. The Ministry of Science, Energy and Technology (MSET) maintains Jamaica's Open Data Catalog (https://data.gov.jm/). The portal was designed to provide public access to information and allow governments, non-profits and universities to share or publish their work. However, the portal currently only provides a limited assortment of primary datasets.

Furthermore, the stakeholders interviewed were unaware of the existence of this database. Therefore, in addition to the Open Data Catalog requiring a detailed inventory of research from state agencies, R&D organisations, universities and NGOs, knowledge and awareness of this portal are also re-

quired. The Open Data Catalog should provide an opportunity to systematically disseminate current research, learn from the successes and failures of previous work, and identify knowledge gaps in each sector. Hence, a national database would offer the advantage of streamlining access to data and improving engagement with funding agencies.

Outcome 3.1 Improved design and implementation of responses to climate change

A nationally accessible database that hosts relevant assessments and studies for academic, public, and private sectors will improve strategic planning for climate impacts. It creates an environment for improved engagement with funding agencies, reduced duplication of work, and improved response time for more significant sustainable economic development. Improve knowledge on the effectiveness of climate finance investments for past and current adaptation and mitigation programs can contribute to improve the resource allocation to target climate change. Learning from a review of the barriers and opportunities could shed light on the pitfalls to avoid and the necessary mechanisms to support plans for future financial investments in climate change adaptation and mitigation.

RT&D activities to address knowledge gaps

- Enhance the integration of climate projections and Disaster Risk Reduction (DRR) across sectors.
- Develop and monitor a data inventory that details the dimensions of vulnerability to climate change impacts on livelihoods and sectors.
- Research the opportunities and barriers to implementing adaptation and mitigation technologies across sectors. The identification and understanding of the barriers will facilitate the definition of strategies for equitable access to green technology for various sectors.
- Improve knowledge on the effectiveness of climate finance investments for past and current adaptation and mitigation programs.
- Continue efforts to improve methods for estimating direct and indirect costs, benefits, and cost-effectiveness of strategies across sectors.
- Through cooperation with public and private research institutions and private businesses, conduct research and development to strengthen and advance technological innovation, business models, and policies.
- Organise assessments and studies in a resource database to promote investment opportunities and foster research and evaluation for proposed projects.

Chapter 4

Research priorities for agriculture and fisheries

Theme 1. Mitigating risk, hazard and climate change

Outcome 1.1: Vulnerability to climate risk and hazards are reduced

Outcome 1.2: Greenhouse gas emissions from the agriculture sector are identified and reduced

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Theme 2. Ensuring climate change resilience and adaptation

Outcome 2.1: The dimensions of resilience and adaptation to climate change are understood and addressed

Outcome 2.2: Climate change impacts within the agricultural sector are understood and managed in the context of likely future scenarios

Outcome 2.3: Stable crop production and improved yield quality under changing climatic conditions

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Theme 3: Developing synergies and reducing trade-offs between food supply, biodiversity and ecosystem services

Outcome 3.1: Food production is achieved through an environmentally sustainable sector

Outcome 3.2: A resilient food system is achieved through the reduction in food loss and food waste

Outcome 3.3: Strengthened role of the agriculture sector within the circular economy and bioeconomy

4. Research agenda for agriculture and fisheries

The agricultural sector plays an integral role in Jamaica's national development's economic, social, climatic, and environmental aspects. Comprised mainly of small and medium-size farmers (Government of Jamaica 2009), the sector has faced a myriad of challenges since the post-independence era. These include high imports, low productivity, market liberalisation, high cost of production, poor and inefficient infrastructure, limited technology, and weakened support services and safety nets. More recently, these challenges have been further exacerbated by the shocks and stresses of changing climatic conditions, including variable rainfall, water scarcity, severe and more frequent storms, drought conditions, and pests and diseases (Climate Studies Group Mona and Planning Institute of Jamaica 2017).

Preliminary empirical research and data collection have also been highlighted as a significant issue within Jamaica's agricultural sector (Government of Jamaica 2009). However, even though some areas require more research and innovation, an Economic and Social Survey Jamaica review (PIOJ 2018) and bilateral interviews with several stakeholders acknowledge the progress made in expanding research and development capacities in the sector. Nevertheless, the relatively slow implementation of research findings remains a perceived challenge within the sector. Like Harris (2015), stakeholders have also highlighted the importance of recognising the two major strands of research across the island, including those conducted by academia, such as the University of the West Indies (UWI), and outputs from various R&D agencies. Studies conducted by academic institutions and disseminated through published journal articles are often conflated with projects carried out by state agencies and NGOs under the broad umbrella of 'research'. However, according to stakeholders interviewed, projects conducted outside of academia may often not implement the methodological rigour required nor meet the publication standards set by peer-reviewed journals.

Furthermore, many public R&D institutions and NGOs often document their work within the sector as reports and summaries. Examples include the Jamaica Social Investment Fund's (JSIF) execution of the Rural Economic Development Initiative (REDI) project, the Planning Institute of Jamaica's (PIOJ) annual research and development surveys, and reports from the Caribbean Climate and Innovation Centre. These reports on climate change innovation have not appeared in peer-reviewed journals. However, they have still been proven valuable in guiding high-level decisions with financing agencies such as the World Bank (WB) and the Caribbean Development Bank (CDB). Conversely, some stakeholders perceived academic research as mainly geared towards generating knowledge for the scientific community and not closely aligned to policy or development targets. Nevertheless, it is critical to acknowledge the contribution of academic institutions, R&D agencies, and NGOs to research and support the collaborative efforts of these bodies to produce knowledge that will generate impact.

Among the main strands of research highlighted, the key challenge of implementing the knowledge generated continues to persist. Local research has unearthed some knowledge that can address some of the significant problems impacting the sector, including drought, low nutrient quality for grazers, low tolerance to changing climatic conditions, and poor soil quality, among others. State R&D organisations such as the Scientific Research Council (SRC) have used experimental genetic modification and molecular diagnostic technologies to investigate the development of high-yielding crop varieties and research the resistance profile of plants to different pests and diseases. Likewise, the International Centre for Environmental & Nuclear Sciences (ICENS) has researched the soil quality across the entire island. Other research activities within the sector include the establishment of a tissue culture facility to support research and the introduction of new varieties; the engagement of the Jamaica Agricultural Commodities Regulatory Authority (JACRA) in experimental trials of coffee varieties in the Blue Mountain and High Mountain coffee growing regions to assess the feasibility of improved plant vegetative and productivity features; research by the Sugar Industry Research Institute (SIRI) on improved sugarcane varieties, and the rearing of bio-control agents under laboratory conditions (PIOJ 2018).

However, according to several researchers and public agency stakeholders, there has been a deficit in responding to the long-standing problems facing the sector on which research has already been conducted. For example, even though research on combatting drought conditions through investments in water catchment or rainwater harvesting systems is available, state investments by sector stakeholders remain insufficient. Similarly, producers – mainly smallholder farmers – are often resource-constrained, posing a challenge for implementing climate-smart knowledge and technologies. Stakeholders further perceived that even though the increased variability and unpredictability of rainfall patterns due to climate change were well known (Guido et al. 2019; Rhiney et al. 2018; Climate Studies Group Mona and Planning Institute of Jamaica 2017), actions aimed at harnessing resources to implement sector-wide adaptation plans have been slow. Likewise, although some knowledge is available on the vulnerability of local crop varieties, the sector has remained unable to widely utilise disease-resistant and drought-tolerant plant strains.

Generally, there is a perception that research results within the agricultural sector are widely available. However, there has been a challenge with the cross-sectoral distribution and transfer of knowledge and research already generated. Currently, research within the sector is characterised as scattered. For example, a stakeholder acknowledged the challenge of sourcing relevant data while conducting a desktop literature review of the different production systems (livestock, crops, beekeeping, fisheries etc.) within the sector. Hazard mapping was also identified by a stakeholder as knowledge already available but yet to be efficiently implemented within mitigation and adaptation programmes. On the other hand, another stakeholder identified this as an area with knowledge gaps requiring further research. As discussed in Chapter 3 (see Theme 3), Jamaica's Open Data Catalog currently houses a limited assortment of data that does not adequately capture the sector's research activities and intervention strategies.

The online platforms of national organisations such as the Rural Agricultural Development Authority (RADA) primarily publish general data on agronomic practices, crop production, post-harvest activities, marketing, livestock management, and pest and disease management. It also attempts to streamline simplified research findings from the Bodles Research Station on adaptation practices and make them available to the farming community through their extension services. The Research and Development Division of the Ministry of Industry, Commerce Agriculture and Fisheries (MICAF) consists of four main subprogrammes: livestock research and improvement, crop research and development, plant protection, and post-entry quarantine. From these subprogrammes, available empirical research covered animal nutrition and feed evaluation, pathology, nematology, entomology, apiculture, field crops, and animal husbandry. However, even though the Division's mandate focuses on 'applying modern technology to increase production and productivity', there has been a lack of recently dated research publications, with available online publication dates ranging from 1995 to 2005. Therefore, even though MICAF's R&D Division has been conducting research, its online database of research documents does not reflect recent discoveries and technical advances in the sector. These include conducting experimental trials on various fungicides and resistant varieties of cacao to combat frosty pod rot – a major cacao disease; developing a line of disease-resistant scotch bonnet peppers; conducting trials on cassava varieties for improved yield and starch content under rainfed and irrigated conditions; assessing soil enrichment through the use of various plants as green manure and cover crop; improving the quality of commercial crops such as onions, citrus, ginger, and root tubers; as well as using total mixed ration (TMR) technology to assess formulations from local fodder sources to increase livestock productivity taking into consideration the impact climate change may have on animal nutrition (PIOJ 2018).

The lack of financial resources was acknowledged as the primary cause of the absence of recent and sufficient research publications. According to stakeholders, as a state agency mandated to conduct research, the Division does not receive an adequate budget for research and development, especially for procuring goods and services. Instead, funding within the Division often depends on providing research services to clients within the agricultural sector, including farmers and stakeholders within the private sector. Research may also be facilitated through various projects and programmes supported by external funders. For example, the Division collaborated with several stakeholders, including RADA and the Meteorological Service of Jamaica, to carry out the Food and Agriculture Organization (FAO) funded Beet Armyworm Management Programme. The project focused on strengthening the monitoring and surveillance of the beet armyworm pest by developing a forecasting system and improving farmers' on-farm crop and pest management practices. Similarly, the Division collaborated with the National Irrigation Commission (NIC) under the Optimizing Irrigation Water Management to Improve Crop Output and Water Quality Control Project. This was intended to improve soil-water interaction, water efficiency, and fertiliser use on various crops.

The Climate Investment Funds (CIF), through the Pilot Program for Climate Resilience (PPCR) project, funded Division research on the resilience and adaptability of livestock to heat stress, including imported and local sheep breeds and the locally bred Jamaica Hope dairy cattle. The Jamaica Hope cattle are a tropical breed that is heat tolerant, resistant to ticks and tick-borne diseases and is not dependent on large volumes of input for milk production. Further research is needed to assess its future adaptability to climate indicators. The CIF funding also helped to refurbish a seed bank at the Division's Bodles Research Station, providing a designated facility to identify, preserve and store climate-resilient crop varieties for the agricultural sector. With its extended seed-producing capacity, the facility would also ensure faster recovery for replanting in the event of a natural disaster. Furthermore, the Division's collaboration with the International Atomic Energy Agency (IAEA) also facilitated stable isotopic techniques to determine soil moisture content and evaluate fertiliser management (PIOJ 2018).

Within the apiculture industry – a relatively under-researched area – the Apiculture Unit of MICAF, in collaboration with the United States Agency for International Development (USAID), funded ACDI/VOCA's Jamaica Rural Economy and Ecosystems Adapting to Climate Change (JaREEACH), which began monitoring environmental conditions using the Arnia Hive Monitor. Designed in Europe, this innovative tool was used to collect data on bee colonies over various periods. However, the instrument failed to hold up in local field conditions. Nevertheless, the three months of data collected from the instrument revealed that even though external temperatures would increase between 12 pm to 1 pm, the temperature inside the hive did not experience any significant increase, with the hive temperature much cooler than the external temperature. This data contributed to hive management and best practices as beekeepers became aware of the periods where hives should remain closed. Otherwise, beekeepers risked placing their bees under stress to regain the hive's cooler temperature, as energy would be exerted to access excessive amounts of water. Therefore, instruments of this nature are critical to monitoring climate interference on beehives.

The agricultural sector has been highlighted as a critical area for implementing mitigation and adaptation activities in response to changing climatic conditions (Government of Jamaica 2015a). Due to the direct impact of climate change on the sector and its livelihoods, local projects and programs have been primarily designed around implementing adaptation strategies. Likewise, published studies and grey literature have focused more on addressing climate change adaptation and building resilience. For example, various research topics within the agricultural sector have explored the role of economic and climatic change on livelihoods. These include the impact of trade liberalisation (Barker 2012; Weis 2006), the risks to food security (Kinlocke et al., n.d.; Beckford, Campbell, and Barker 2011; McGregor, Barker and Campbell 2009), the vulnerability of rural livelihoods (Birthwright and Barker 2015; Gamble et al. 2010; Campbell, Barker and McGregor 2011), the disparities in adaptation strategies (Tomlinson and Rhiney 2018; Birthwright 2016a; Campbell, Barker and McGregor 2011),

the development of suitability models (Rhiney et al. 2018; Eitzinger et al. 2013; Campbell, Barker and McGregor 2011), the link between bushfires and climate variability (Campbell, Barker and McGregor 2011), and the role of climate services (Guido et al. 2019), among others.

As a party to the United Nations Framework Convention on Climate Change (UNFCCC), Jamaica submitted its first Biennial Update Report (BUR) in 2016. The inventory report consisted of technical analysis of GHG emissions and storage for the island's sectors between 2006 to 2012 (Mahlung and Dore 2016; Patterson 2016). Additionally, ICENS (2021) has researched carbon dioxide emission from soils within the agriculture sector, particularly since 'Soil organic matter (SOM) contains more carbon than the atmosphere and terrestrial vegetation combined'. However, according to several stakeholders, the sector's progress toward addressing GHG emissions is still in the early stages, especially since Jamaica is not a significant global contributor. Furthermore, there has been a lack of empirical research to address possible mitigation strategies and opportunities within the sector.

According to Josling et al. (2017), 'no amount of mitigation in Jamaica alone is likely to have any measurable impact on Jamaica or its agricultural sector: the vulnerability of Jamaica and its agriculture sector to climate change depends on the actions of other countries'. Hence, though local stakeholders have acknowledged the importance of mitigation plans, the need to develop or implement strategies to reduce emissions has not been perceived as a significant priority. Furthermore, considering the island faces the brunt of the impacts of climate change, the focus has been on developing sound adaptation plans and strategies that would facilitate livelihood survival and sustainability.

An examination of policy documents and stakeholder interviews has also shown that, even with a general acknowledgement of the impacts of climate change on the agricultural sector, local multi-scalar empirical research has been integrated into policies and programmes only to a limited extent. Nevertheless, the multiple adaptation strategies and mitigation action plans proposed to address the various climatic challenges have been informed by local stakeholder consultations and international research, and successful programmes have been conducted and implemented in other regions. For example, the agricultural sector has benefitted from several adaptation projects, such as those implemented under the Government of Jamaica/Adaptation Fund Programme (GOJ/AFP). Climate adaptation projects have also been carried out by JaREEACH, promoting rural livelihoods and ecosystems through interventions to increase and strengthen climate change resilience. Similarly, the National Environment and Planning Agency (NEPA) has also implemented initiatives to build awareness of the negative impacts of farming practices in watershed areas, leading to the destruction of ecosystems and habitats. The Forestry Department has also encouraged communities to adopt reforestation measures, protect ecosystem services through agroforestry, and educate communities on the relationship between various organisms (flora and fauna). However, according to interviews with sector stakeholders, though these efforts are commendable, the benefits from these projects

are often short-lived and disappear after the project cycle or when project funds expire, impacting livelihoods and environmental sustainability. Stakeholders also acknowledged that most of these projects do not possess a primary research component but are designed and executed based on secondary data collection, hindering the potential generation of new knowledge and research value.

Therefore, stakeholders have highlighted the need to move away from the 'copy-paste' approach to climate resilience within the sector, involving the adoption and replication of approaches from other countries. Instead, it is vital to develop a plan that is specific to Jamaica, strengthen research capacities by improving local efforts to access funding, and establish new research mandates. The complexities of agricultural systems and their role in GHG emissions, the vulnerability of rural livelihoods, the site-specificity of climatic impacts, and the difficult political, environmental, and socio-economic conditions mean that a broad range of empirical research and methodologies need to be defined for the sector, within the Jamaican context. Likewise, even though there is a general acknowledgement of the need to strengthen research for development within the agricultural sector, there remains a vague understanding of how the identified knowledge gaps will be filled. A definitive focus on the methods required to implement this research agenda within different subsectors is also vital for tailoring intervention programmes and plans in order to facilitate long-term development of the sector. Consequently, establishing an enabling environment within the sector that promotes strong links between research and policymaking and encourages sustainability is of great importance.

Chapter 4. Research priorities for the agriculture and fisheries sector

Theme 1. Mitigating risk, hazard and climate change

Outcome 1.1: Vulnerability to climate risk and hazards are reduced.

Outcome 1.2: Greenhouse gas emissions from the agriculture sector are identified and reduced.

Theme 2. Ensuring climate change resilience and adaptation

Outcome 2.1: The dimensions of resilience and adaptation to climate change are understood and addressed.

Outcome 2.2: Climate change impacts within the agricultural sector are understood and managed in the context of likely future scenarios.

Outcome 2.3: Stable crop production and improved yield quality under changing climatic conditions.

Theme 3. Developing synergies and reducing trade-offs between food supply, biodiversity and ecosystem services

Outcome 3.1: Food production is achieved through an environmentally sustainable sector.

Outcome 3.2: A resilient food system is achieved through the reduction in food loss and food waste.

Outcome 3.3: Strengthened role of the agriculture sector within the circular economy and bioeconomy

Figure 5. *Research themes and outcomes for the agriculture and fisheries sector*

Theme 1: Mitigating risk, hazard, and climate change

Agriculture has been an important source of income for the rural population. However, several factors have influenced the significant decline of Jamaica's traditional agricultural sector and perpetuated the socio-economic challenges now confronting rural communities. Rural areas across the island host some of the most vulnerable human populations (Dunn and Senior 2009) and have a 20% poverty prevalence (Statistical Institute of Jamaica 2017). The impacts of meteorological events such as hurricanes, floods, and droughts, as well as changing climatic conditions, have further compounded these challenges: farming livelihoods face high exposure and risk, and various links along food supply chains may also be threatened. For example, in 2017, the sector experienced widespread flooding and landslides associated with extremely heavy rains from March to June. Damages to the sector were estimated at J$796.4 million, as farmers across the island experienced the loss of crops and livestock. Likewise, fishermen were also negatively affected as they could not launch their vessels due to the accumulation of debris (PIOJ 2018). Other possible impacts include the exacerbation of high production costs, the effects on food prices, access and affordability, the disruption of post-harvesting and marketing activities, and the worsening of poor farm infrastructures and transportation routes.

Furthermore, considering that women represent 70% per cent of individuals residing below the poverty line, poor women are more vulnerable to the impact of natural hazards. They are heavily burdened in the aftermath of disasters (Dunn and Senior 2009). However, the Jamaican context has limited knowledge of empirical work on this topic within the disaster management field and the climate change arena.

The agricultural sector's vulnerability to climate change is widely known but it is also one of the primary sources of GHGs, including carbon dioxide, methane, and nitrous oxide. However, the sector is also able to trap these emissions. This is often dependent on the quantity and extent of available sinks compared to the existing sources of these gases, land use practices, soil management, crops, manures, livestock, and energy use (Pant 2009). Jamaica's contribution to GHG emissions is minor compared to that of larger countries within the Global North (Filho and Mercer 2017; UNFCCC 2005). Nevertheless, despite limited research on appropriate mitigation strategies within the Jamaican context, national policy documents have outlined plans to reduce GHG emissions while maintaining economic development. Generally, a significant carbon sink for the island is to be found in land use, land-use change, and forestry (LULUCF) activities, offsetting around 11% of gross emissions in 2012 (USAID 2017). Stored biomass within the forestry sector is particularly significant but the sector's emissions remain uncertain due to the challenges associated with accurately quantifying changes to natural ecosystems.

While Jamaica's agricultural sector contributes substantially to local GHG emissions (USAID 2017), carbon dioxide emitted by the energy sector dominates the GHG emission total. However, gasoline and diesel oil emissions for various agricultural machinery also occur (Mahlung and Dore 2016). Most

on-farm nitrous oxide emissions are driven by changes in annual livestock numbers, which in effect impacts manure management emissions and emissions from soils (with the use of organic fertiliser or synthetic fertiliser). Though making a comparatively small contribution to the total GHG emission inventory, enteric fermentation and manure management produces the most significant contribution to total methane emissions. The dominance of enteric fermentation is primarily attributed to cattle (dairy and non-dairy), yet three-quarters of methane emissions from manure management in 2012 were contributed by pigs and poultry (Mahlung and Dore 2016).

A 2017 IDB report on agricultural policy and greenhouse gas emissions in Jamaica further expanded analysis by highlighting whether domestic policy incentives were counterproductive to achieving mitigation goals to reduce GHG emissions from the sector (Josling et al. 2017). For example, poultry production is the island's main livestock subsector, followed by pork. Even though the poultry industry contributes a sizable amount of GHG emissions, mainly from manure management (Josling et al. 2017), the industry has experienced substantial growth since it enjoys high levels of support through import protection measures (customs duties, addi-tional stamp duties, sanitarian requirements) and subsidised loans (Shik, Boyce, and De Salvo 2017). For example, Caribbean Broilers' newly launched Hybrid Growth Centre, also dubbed the Nest Project, has been designed to use liquified natural gas (LNG) instead of other fossil fuels. This will reduce their carbon footprint, since LNG burns 50-60% less carbon dioxide and produces minute levels of sulphur dioxide and particulate matter (Environmental Solutions Limited 2018).

Similarly, sugar cane also experiences high support measures from farm policies and contributes substantially to GHG emissions per hectare, followed by bananas and yams. Consequently, it may appear that maintaining these protection measures is not entirely consistent with goals to reduce GHG emissions. However, it is crucial to analyse these measures through the broader lens of sustainable development, mainly since Jamaica is a vulnerable Small Island Developing State (SIDS) operating within a global free trading system. Therefore, within the context of achieving the Nationally Determined Contributions (NDC) targets, the relationship between high GHG emitting sectors and policy support must be addressed with a nuanced understanding of national food security, income generation, and sustaining livelihoods. Josling et al. (2017) therefore made several recommendations that may mitigate GHGs emissions while advancing economic growth and the sustainability of crop and livestock farming across the agriculture sector. These recommendations ranged from implementing policy changes to adjusting management techniques.

The Research and Development Division of MICAF conserves local animal genetics for beef, dairy, and pork. According to stakeholders, even though feed concentrates facilitate a higher production of methane gas, they play a significant role within the dairy industry, contributing to milk production and being an economical source of nutrients. However, the Division focuses on improving forage

systems, promoting animal diets that focus on forage, and the livestock subsector is currently being encouraged to become increasingly pasture-based. Regarding crop cultivation, strengthening data collection capacities to capture fuel and energy use per crop and the positive contribution of crops, especially tree crops, to GHG sequestration is also important.

Data gathering mechanisms that capture microclimatic data better to inform farmers and other stakeholders within the agriculture sector was also identified as an area that requires further research. Microclimates characterise the island due to its topography. Consequently, climatic challenges facing farmers in one section of the island may differ from those in other areas. Stakeholders interviewed called for the increased installation of automatic weather stations (AWS). They acknowledged the gap in climate and weather data for the rural interior. The Climate Studies Group Mona (2017) also recognised the methodological constraints that "inadequate climate observation station coverage over the island" posed in conducting research. However, according to stakeholders from the Meteorological Service of Jamaica, the agriculture sector has benefitted from installing AWS in several farming communities across the island. The selection of station installation sites is usually a collaborative effort between the RADA and the Meteorological Service of Jamaica, where the former may select potential sites. At the same time, the latter would guide in terms of suitability, mainly since some areas may be unsafe or inaccessible.

Even though strides have been made in advancing local meteorological forecasts and services through the improvement and expansion of AWS island-wide, gaps remain in collecting agroclimatic datasets and the limited use of the datasets currently available. Progress in these areas could also support research in modelling scenarios, leading to further information for improved decision making at the local and national levels, such as the suitability of crops in different areas under changing climatic patterns.

Not everyone will experience adverse effects from climate change. For example, beekeepers in the parish of Portland – a characteristically wet area – may experience drier conditions that would positively impact their production. A dissimilar occurrence in southern St. Elizabeth – a characteristically drier area – where farmers would encounter a negative response on output due to excessively warmer conditions. Therefore, it is necessary to capture comprehensive data on the various micro-climatic zones across the island and observe their patterns, their influence on crops, and how climate change will affect them.

USAID's Technical Report also highlighted the lack of good climate information services. This gap in knowledge and technology remains a significant hindrance for local and national stakeholders to enhance adaptive capacity and implement proactive measures. Filling this gap requires a multi-stakeholder collaborative effort in "improving climate information services' content, design and delivery

to increase users' understanding of short- and long-term forecasts and climate projections, their impacts, and how to respond to them through policies, initiatives, or on-the-ground measures to increase resilience" (Ashley, Dahodwala, and Dreiling 2019). The Meteorological Service of Jamaica has established a capacity in forecasting but further expansion is needed in this area. Recently, a collaboration between the Meteorological Service of Jamaica and the Climate Studies Group, Mona (CSGM), was launched under the Pilot Programme for Climate Resilience (PPCR) and the Improving Climate Data and Information Management Project (ICDIMP). The installation of an Automatic Weather Station (AWS) on the Mona Campus will facilitate an improvement in "the quality and use of climate-related data and information for effective planning and action at the local and national levels" (UWI Mona 2021). Stakeholders from the Meteorological Service of Jamaica have suggested expanding the access and availability of weather instruments to agricultural producers outside the organisation's AWS network. This would increase the density of weather instruments and data access points across the island and contribute to broader climate change analysis and research.

Further research to transitioned from traditional housing infrastructures to those designed to withstand certain hazard events, such as storms and hurricanes, within the private sector is also needed. Large boiler operators have already implemented these hazard-resilient infrastructures, referred to as 'tunnel houses,' are also being utilised by contract farmers associated with these large private broiler entities (The Jamaica Observer 2018).

Outcome 1.1: Vulnerability to climate risk and hazards are reduced

RT&D activities to address knowledge gaps

- Enhance multiscalar mapping and research on food security risk due to the impacts of climate change on rural and urban environments.
- Improve understanding of how effective the response to existing hazard mapping approaches has been. These approaches highlight the most critical areas for better adaptation planning for climate change impacts.
- Develop disaggregated data to understand the vulnerability of rural and urban agriculture to climate-induced hazards (social, economic, political, environmental, institutional, etc.). In particular, studies are needed to capture the broad components that influence marginalisation and the underprivileged and how these translate into livelihood vulnerabilities. This also includes research on the lived poverty experience and some of the nuances of poverty that may push individuals to engage in unsustainable practices that contribute to climate change and make them more vulnerable to its impacts.
- Improve climate information services' content, design and delivery to increase users' understanding of short- and long-term forecasts and climate projections, their impacts,

and how to respond to them through policies, initiatives, or on-the-ground measures to increase resilience.

- Improve access to low-cost weather data collection instruments for collecting agroclimatic parameters.
- Enhance research on climate and hazard-resilient agricultural infrastructure (rural and urban) to reduce economic and social losses caused by natural hazards and shorten recovery time. This also expands into the research of greening agricultural infrastructures to reduce energy costs, such as packaging facilities, warehousing, and storage facilities, including cold storage.
- Improve climatic impacts measurement tools and valuation methods for agroinsurance producers, especially considering the agricultural sector's vulnerability. The lack of a broad-based insurance scheme for the sector has hindered economic investments. Hence, any product development that can be accrued from additional analysis or research in the areas of measurement and valuation should be undertaken and should be equitable in its application.

Fisheries

- Enhance research on climate and hazard-resilient fisheries equipment and infrastructures to reduce economic and social losses caused by natural hazards, shorten recovery time, and minimise energy costs.
- Improve climatic impact measurement tools and valuation methods for equitable agroinsurance for fishers' livelihoods and those involved in aquaculture.

Outcome 1.2: Greenhouse gas emissions from the agriculture sector are identified and reduced

RT&D activities to address knowledge gaps

- Capture consistent and comprehensive data on changes to livestock and arable farming practices and their effect on emissions, which will encourage the implementation of efficient monitoring and evaluation systems.
- Improve knowledge of the economic benefits associated with the sequestration of local GHG through sustainable land management (e.g. agroforestry).
- Expand research on Jamaica Hope cattle (e.g. on methane inhibitors) to demonstrate how this tropical animal, initially bred for small farmers, can mitigate climate change and produce more comprehensive economic benefits.

- Develop research on measurements of GHG emissions and carbon sequestration of urban agriculture.
- Improve methodologies to capture consistent and comprehensive data on the emission and sequestration of GHG of individual crops (traditional and non-traditional).
- Capture disaggregated data on emissions from the primary production of crops and livestock (e.g. land preparation, fertilizing, weed control, agrochemical use, harvesting, processing, transportation). This assessment would identify the activities or practices that contribute to or mitigate emissions in each subsector.
- Conduct research to improve pasture-based systems for ruminants while also managing the landscape as a carbon sink, since well-managed pastures act as a vehicle for sequestering carbon from the atmosphere.
- Quantify the environmental benefits of maintaining and implementing sustainable land management practices. This includes improving local knowledge on soil services under climate change. Soil is not only a medium in which plants grow, but it is also an ecosystem services provider. Hence, approaches to sustainable land management practices which encourage profit optimisation rather than profit maximisation through over-exploitation are necessary throughout the sector.

Fisheries

RT&D activities to address knowledge gaps

- Capture consistent and comprehensive data on changes to practices in the fisheries subsector concerning their effect on emissions, which will encourage the implementation of efficient monitoring and evaluation systems.
- Capture disaggregated data on the emission from the fisheries subsector (such as fuel for fishing vessels, energy used by aquaculture machinery, and infrastructure).
- Research innovations to improve fuel efficiency through the improved engine or vessel design. This may also include experimenting with alternative fuels for the fisheries subsector and whether adoption by fisher folks would engender long-term sustainability.
- Research how to improve and increase fish stock or biomass closer to land, mainly through Special Fisheries Conservation Areas and other strategies.

Theme 2: Ensuring climate change resilience and adaptation

The agricultural sector is an important contributor to GDP, employment, foreign exchange earnings, and rural livelihoods in Jamaica. Even though agriculture represents approximately 7% of the total GDP, around 15.7% of the active population are directly employed in the sector (Statistical Institute of Jamaica 2021), and 44% of the population resides in rural areas (World Bank 2019). Most farms across the island are rain-fed, though irrigated agriculture supplies around 50% of national food production and contributes to the development and incomes of rural communities (Government of Jamaica 2019). Consequently, it is important to the country's economic development. Increasing adaptation and strengthening resilience at the local level requires an enabling environment that fosters access to resources (financial, technical and human). Also, the incorporation of indigenous knowledge within the sector strategies is especially important considering that various areas across the island may utilise specific local knowledge.

Climate change adaptation and building resilience extend beyond knowledge towards ensuring that individuals possess the resources and financial ability to implement suggested measures. In tackling the effects of climate change, therefore it is critical to address rural poverty.

With regards to urban agriculture, there is no data on the status of urban agriculture (crops/livestock/apiculture) and associated livelihoods within towns and cities across the island. There are wide knowledge gaps on the viability and sustainability of urban agriculture that require research. For example, identifying some of the cultural and geographical barriers that hinder the expansion of urban agriculture; researching the extent urban agriculture, and how it contributes to food security; identifying socio-economic and environmental factors that affect engagement in urban agriculture and assessing the implications for urban agriculture in a water-stressed environment.

The agricultural sector produces several traditional crops for exports, including coffee, citrus (fresh fruits), pimento, cacao, sugar, and bananas, of which coffee accounts for one of the largest foreign exchange earnings. In 2019 coffee represented 74% of total agricultural exports for the island. The same year, pimento accounted for 14.1%, citrus 5%, banana 3.6%, and cacao 2.8% (Statistical Institute of Jamaica 2019). However, due to the decline in traditional agricultural exports, especially coffee and citrus, there have been efforts to stimulate the production of non-traditional export commodities, including root tubers such as yams and sweet potatoes, as well as fruits such as papayas and ackees (Shik, Boyce and De Salvo 2017). Earnings from non-traditional exports increased by 43% between 2015 and 2019 (Statistical Institute of Jamaica 2019).

As a climate-sensitive sector exposed to external shocks, the impact of climate change on agriculture has become a significant concern. The variability in temperature and rainfall patterns, the occurrence of frequent natural hazards such as hurricanes and prolonged drought conditions, as well as increased pests and diseases, may significantly impact yield production, water availability to food crops, agricultural sustenance, rural livelihoods, and inevitably the nation's food security (Selvaraju and FAO 2013). Over the years, the agriculture sector has been impacted by several storms and hurricanes. The Office of Disaster Preparedness and Emergency Management (ODPEM) has an established response system for these events. However, "a gap remains in forecasting drought, flooding, and pests and diseases" (Ashley, Dahodwala and Dreiling 2019). Hence, agroclimatic monitoring and modelling are needed to prepare better the sector and its livelihoods for responding to these disasters.

The microclimatic and soil variability across the island suggest the need for knowledge of agricultural water demand and the unique irrigation requirements for various crops cultivated. Developing irrigation demand guidelines for various subsectors and according to seasonality will inform irrigation planning and water management strategies during times of water scarcity. Generally, irrigated agriculture consumes a significant portion of ground and surface water resources (Government of Jamaica 2019). However, there is a lack of knowledge around crop water requirements and daily reference evapotranspiration to guide farmers on the optimal use of their water resources, especially considering that water requirements vary throughout the crop life cycle the crop variety, soil type, rate of evapotranspiration, etc. Extension officers may use tensiometers (a measuring instrument used to determine the soil water potential or availability in the vadose zone for plants) on farmers' plots. However, this only gives a snapshot of the soil-water condition for a specific period and does not offer sufficient information to guide daily watering activities. Hence, cost-effective technology capturing continuous agroecological data is needed to advise users of daily irrigation requirements. Without this guide, farmers often over-water or even underwater their crops, thus impacting productivity. This may even contribute to reducing farm inputs while increasing productivity. Other possible research strategies include field experiments and crop simulation to evaluate and test yield responses to different water scenarios.

When facing drought, research on drought-tolerant cultivars (traditional and non-traditional crops) that can produce at economically viable levels before they are introduced to farmers is needed. This research should consider varieties that can result in year-round rather than seasonal production. Some of the crop varieties available on the local market are not only costly but are sometimes not adaptable to the island's local conditions, depending on where they were bred and evaluated. Over the years, the R&D Division at MICAF has evaluated imported varieties or cultivars to determine their adaptability for farmers' use. While plant species will be negatively affected by temperature increases, others may be positively affected. Experimental research on these species is needed to discover how they can be economically beneficial to the sector on a broader scale and contribute to the nation's food basket.

With regards to the apiculture industry, improved instruments for capturing critical documentation about pests and climatic parameters are required. The general pattern of plant flowering spans from November to May, while the 'dirt period' where no major plants are blossoming occurs from June to September. Hence, when food for the bees is limited, beekeepers must ensure that colonies are kept alive by feeding them with an energy source such as sugar. Pollen supplements are also provided, which contain protein and minerals. From a research perspective, improving knowledge of the island's vegetation management system is needed. For the apiculture industry a better understanding of the relationship between pests, the parameters of climate change, and how hive management strategies are implemented is a priority. For example, red ants are considered one of the most dangerous pests to honeybees, when they invade the hives for warmth and food. Similarly, an increase in Cuban tree frogs – an invasive species – has been observed across the island. These were observed during periods of heavy rainfall. Generally, since the local Jamaican frogs cannot jump significant heights, hives are often set at 16-18 inches off the ground as a management strategy. However, Cuban frogs can jump to great heights, including the top of hive covers, where they enter and affect bee colonies.

Improve knowledge on how changing climatic conditions (frequent drought, higher temperatures, variable rainfall, etc.) have affected the frequency and range of pests and diseases on economically valuable crops. Warmer temperatures often result in shorter cycles for some pests, which may increase their replication within a cropping season and destroy the crop. For some private operators in the agricultural sector who also employ contract farmers, technologies are used to safeguard their production from pests and diseases. For example, poultry operators utilise climate-controlled houses that protect birds from conditions suitable for spreading pests and diseases. Other private operators also engage in the protected agricultural method for crop production using greenhouses. However, it was found that even with these safeguards, increased external temperatures lead to higher energy consumption to ensure that these climate-controlled houses can function.

Furthermore, in conjunction with warming and drying trends, the island is also expected to experience a sea-level rise, especially along the northern and southern coasts. This may result in a loss of agricultural lands due to direct erosion, temporal flooding and contamination of the agricultural soil via salination (Eitzinger et al. 2013), impacting livelihoods. Similarly, for the fisheries subsector, climate change may threaten coastal communities, the livelihoods of fisher folks, and sector-related infrastructure. Currently, the most economically important species harvested are conch, shelf and reef fish, pelagic species, lobster, and shrimp. According to the Planning Institute of Jamaica (2019), the Fisheries Division in MICAF conducted an abundance survey of the Queen Conch (Strombus gigas) in 2018 to assess the health and status of Jamaica's conch stock on the Pedro Bank, as well as to determine the total allowable catch for future fishing seasons. Preliminary outputs from the survey

revealed a general reduction in conch stock. Research is also needed on these species concerning their response to the impacts of climate change within the Jamaican marine environment. This also includes enhancing research on the effects of climate change on the coastal zone, including sea-level rise, sea surface temperature, ocean acidification, and the effects on coral reefs, seagrasses, and mangroves, mainly since fish and other marine life rely on coral reefs and mangroves as their habitat. Jamaica relies on the coastal zone for the fisheries sector and the tourism industry so the health of the coastal zone is vital.

Improve information on stock abundance, migration patterns, habitat quality, and ecological carrying capacity. There are no stock abundance estimates for any large pelagic species in the vicinity of Jamaica, including yellow-fin tuna, albacore, blue marlin, and swordfish, to name a few. The best sources of information on the abundance of pelagic fishes in the waters of Jamaica relative to other areas of the Caribbean are the UNDP/FAO Caribbean Fisheries Development Project (CFDP) surveys and the commercial fishery data from the International Commission for Conservation of Atlantic Tunas (ICCAT) (Kellier 2015; Mahon 1995). The lack of detailed information hinders fishery development and management plans.

However, even though programmes promoting resilience and adaptation within the agricultural sector have been evident, such as adopting root and tuber crops that offer more long-term resilience, some areas remain under-researched.

Outcome 2.1: The dimensions of resilience and adaptation to climate change are understood and addressed

RT&D activities to address knowledge gaps

- Improve understanding of the relationship between climate change impacts and rural poverty.
- Strengthen research on the impact of climate change on gender, youth, elderly and disabled in various subsectors, considering their unique socio-economic circumstances, which hinder their adaptation and recovery.
- Research on the intersection between climate change impacts and malnutrition.
- Research on the opportunities and barriers to adaptation and mitigation technologies in subsectors. This will also improve equitable access to green technology for various subsectors.
- Enhance knowledge on how sector-wide ICTs can be used to improve the inventory and accessibility of the reports on adaptation and resilience projects, plans, and interventions already conducted and implemented.

- Improve research on the incorporation of indigenous knowledge within the sector.
- Increasing research on incorporating indigenous knowledge and innovation into programmes may also encourage equitable knowledge and technology transfer.
- Research on the role of beekeeping in the socio-economic operation of livelihoods within rural and urban communities.
- Data on the status of urban agriculture (crops/livestock/apiculture) and associated livelihoods within towns and cities across the island.
- Expand multiscalar research on climate-proofing value chains in various subsectors, including quantifying risks and opportunities across value chains.
- Improve knowledge on the effectiveness of climate finance investments for past and current adaptation and mitigation programs.
- Improve knowledge on the design and implementation of innovative methods for producers to access low-cost financing to maintain and expand their livelihood strategy.
- Provide investment and research for cost-effective and robust tools to monitor climate impact on beekeeping.
- Improve research on plants beneficial to bees, such as the logwood, and their risk to climate change and deforestation.
- Identify opportunities to diversify the vegetation used as a food/floral source of nectar during the dirt period.
- Improve local research on the anti-microbial properties of Jamaican honey and its relationship to the existing vegetation. This could lead to an improved management strategy of re-populating areas with these vegetation types.

Fisheries

- Improve knowledge of the local impacts and vulnerabilities of climate change on the livelihoods operating in the fisheries subsector. Lack of research can hamper adaptation planning at the community and national levels.
- Enhance research on the role of ICTs in the efficient diffusion of knowledge and technology within fishing communities.
- Capture reliable and consistent data on long-term changes in fish catch, where repeated measures for specific fishing communities are available.

- Research various species of seafood with potential for mariculture within the context of reducing water pollution, overfishing, and adapting to changing climatic conditions (e.g. sea-level rise, frequent and intense storms). This may include transferring mariculture operations on land using tanks filled with seawater. Increased understanding of how climate change will affect the health of these species is also needed.
- Research various marine plants (e.g. seaweeds, sea vegetables) as a potential economic resource for the subsector. Increased sea surface temperature favours the growth of marine plants, which may provide another livelihood source for coastal communities.
- Improve information on stock abundance, migration patterns, habitat quality, and ecological carrying capacity.

Outcome 2.2: Climate change impacts within the agricultural sector are understood and managed in the context of likely future scenarios

RT&D activities to address knowledge gaps

- Continue efforts to develop and strengthen local level projections of agroclimate data to address locally specific vulnerabilities.
- Enhance research on the role of ICTs in the efficient diffusion of knowledge and technology within agricultural communities.
- Enhance modelling research on the economic costs of climate change on the agriculture sector (including costs disaggregated for various subsectors and consumers).
- Through cost-benefit analysis, improve the total economic value of long-term green/low carbon investments for adaptation and mitigation in agricultural subsectors.
- Maintain and enhance crop suitability and yield projections under future climate scenarios, at various geographical scales, and for the subsectors of high-value crops (e.g. citrus, coffee). For example, climate change can affect temperature gradients at higher altitudes, thus impacting the quality and quantity of coffee production.
- Improve knowledge on early warning systems for plant disease and weather impacts on subsector crops to enable preventative action.
- Undertake forecasting research for the apiculture industry on the relationship between pests, the parameters of climate change, and how hive management strategies are implemented.
- Capture forecast data on the availability of water sources for the agricultural sector (rural and urban).

Outcome 2.3: Stable crop production and improved yield quality under changing climatic conditions

RT&D activities to address knowledge gaps

- Climate change decreases crop productivity, resulting in price increases for many important crops, thus further impacting food security. Research on approaches to managing food prices during these times is required.
- Capture data on climate-proofing the island's agroproduction zones, including Agro Parks, to ensure continued economic benefits while reducing energy costs and GHG emissions.
- Expand knowledge on quantifying the use of rainwater harvesting and irrigation technologies as suitable adaptation measures to maintain and improve income generation from crop production within rural and urban communities across the island.
- Improve knowledge on how changing climatic conditions (frequent drought, higher temperatures, variable rainfall, etc.) have affected the frequency and range of pests and diseases on economically valuable crops.
- Research on how higher temperatures may affect the efficacy of pesticides. Furthermore, the abuse of pesticides by farmers may also contribute to the selection pressure of particular organisms, which, combined with any favourable environment associated with climate change, can generate a cycle of negative impact on crops.
- Increased research and efficacy trials on drought-tolerant cultivars (traditional and non-traditional crops) that can produce at economically viable levels before they are introduced to farmers, as well as on varieties that can result in year-round rather than seasonal production.

Theme 3: Developing synergies and reducing trade-offs between food supply, biodiversity, and ecosystem services

The agricultural sector is not only a major consumer of energy and water but also poses significant environmental threats. This theme follows the research theme of Gøtke et al. (2015), explaining the dependence of agriculture on natural resources, which often results in economic survival outweighing environmental sustainability. Steep slopes and fragmented landscapes characterise agricultural activities. This has led to the loss of biomass through deforestation, soil erosion and degradation, water pollution, encroachment on forested lands, and the loss and disruption of biodiversity (Birthwright 2016a). For instance, research on achieving a synergetic relationship between the apiculture

industry and infrastructure development is important. There has been widespread infrastructural development across the island, where vegetation removal has impacted the bee population and the livelihoods of beekeepers. Hence, competition and conflict between the natural environment and development have been brewing. Research on this topic is particularly vital since a lowered bee population can impact the pollination of cucurbit plants such as pumpkin, cucumbers, and watermelon. These are important to farmers' livelihoods and the food security of the agricultural sector.

Similarly, the island's fisheries subsector has experienced severe overfishing resulting in depleted fish stocks, damage to habitat, and loss of aquatic biodiversity. According to the Agriculture Sector Plan for Vision 2030, Jamaica's marine resources are threatened by unsustainable harvesting and inadequate fisheries management. The island's marine waters have also been declared among the most over-fished in the CARICOM region (Waite et al. 2011). The impacts of climate change are expected to exacerbate environmental challenges, including increased soil erosion and land slippage due to intense rainfall, the loss of soil fertility due to droughts and soil degradation, as well as increased deterioration of watersheds stemming from efforts to maintain economic activities (Government of Jamaica 2015b).

The livestock sector contributes approximately 14.5% to greenhouse gas emissions (Gerber et al. 2013). There have consequently been calls for consumers to adjust their dietary choices by reducing their consumption of animal products (Schiermeier 2019; Shukla, et al. 2019). However, this action deviates from many societies' cultural and social norms. It sheds light on possible underlying socio-economic factors that may inhibit access and affordability to low carbon diets. Therefore, it is important to assess this implication within the Jamaican context, especially considering the impact on the food security of poor households. This may also shed light on the mobilisation of agency and power relations between actors within the food system.

Stakeholders identified food loss and food waste as part of building a resilient and sustainable food system. Food loss and waste are responsible for approximately 8-10% of global greenhouse gas emissions between 2010 and 2016 (IPCC 2019). For high-income countries, greater volumes of food are wasted throughout the packaging, distribution, and consumption stages. In contrast, low-income countries experience food waste mainly in the production and post-harvesting stages (Food and Agriculture Organization 2015). For Jamaica, research is needed to quantify greenhouse gas emissions from food loss and waste within the agricultural sector. This can further lead to research on the innovative approaches and technologies that may be affordably adopted to reduce or reuse the methane emission from food loss and waste (e.g. for electricity generation). The concept of food waste is not mentioned in the island's policy documents. However, programs such as the 'Agro-Economic Zone'

were established in the breadbasket parish of St. Elizabeth to reduce food waste in Jamaica (The Gleaner 2016). Food wastage is linked to the environment through the loss of biodiversity and the wastage of energy and water used along the supply chain, from farm to fork. Hence, reducing food waste improves the environmental sustainability of food production and, inevitably, food security.

Research on field-level food loss is uncommon and challenging to conduct (Baker et al. 2019). Stakeholders interviewed perceived that the island's agriculture sector has limited field-level food loss due to farmers using unsold produce as animal feed. At the same time, wastage mainly occurs at the table, where consumers throw food away. Regardless, there is a lack of research and statistical data to address these perceptions and inform potential solutions. Hence, research is needed on the approaches that can be implemented to reduce field-level food loss, especially when there are gluts in the market. Likewise, knowledge of the barriers and opportunities for adopting these approaches is also required.

Outcome 3.1: Food production is achieved through an environmentally sustainable sector

RT&D activities to address knowledge gaps

- Research whether adaptation practices increasing food production provide synergies or trade-offs for ecosystem services and biodiversity.
- Improve methods for monitoring and evaluation mechanisms that assess the application of conservation practices throughout the sector.
- Improve knowledge of the links between food security and biodiversity to discover synergies that will generate multiple social, economic, and ecological benefits.
- Improve knowledge on the spatial distribution of ecosystem services, how the trade-offs change over time, and how they interact with structural changes in the agricultural sector, particularly concerning climate change impacts.
- In researching the introduction of new and resilient varieties, it is also important to examine their impact on the local flora and fauna, their quality, and their productivity compared to those already being utilised.
- Research on managing trade-offs through modelling approaches that quantify the consequences of agricultural land-use changes on the provision of ecosystem services over time, considering various economic, environmental, and climatic variables.
- Research on achieving a synergetic relationship between the apiculture industry and infrastructure development.

Fisheries

- Improve knowledge that addresses monitoring and oversight challenges, to ensure that the fisheries and aquaculture subsectors are sustainable and trade-offs between food supply and aquatic ecosystems are reduced.

Outcome 3.2: A resilient food system is achieved through reduction of food loss and food waste

RT&D activities to address knowledge gaps

- Conduct research on the dimensions (social, economic, cultural, political, and environmental) of food loss and food waste as part of building a resilient and sustainable food system.
- Carry out research on the intersection of local dietary patterns, poverty, and reducing greenhouse gas emissions.
- Research each segment of the supply chain within subsectors for food waste and opportunities for reduction. Currently, it is uncertain how much food is wasted relative to how much food is produced.
- Improve research on controlling peaks and troughs in the market to control food loss. Post-harvesting technology research allows farmers to store excess produce and distribute it over more extended periods to avoid food loss or food waste.
- Quantify greenhouse gas emissions from food loss and waste within the agricultural sector.
- Research on the innovative approaches and technologies that may be affordably adopted to reduce or reuse the methane emission from food loss and waste (e.g. for electricity generation).

Outcome 3.3: Strengthened role of the agriculture sector within the circular economy and bioeconomy

RT&D activities to address knowledge gaps

- Improve knowledge on pathways for sustainable food waste management while contributing to the circular economy.
- Expand research on participation within the circular economy by utilising waste from pasture-based systems to reduce emission contributions further.

- Several stakeholders within the agricultural sector have integrated their operations within the circular economy. For example, they are reusing manure waste from chicken houses to fertilise plants and crops. The Caribbean Broilers' The Nest project, for example, has been designed to operate within a circular economy and bioeconomy. Usually, their chicken carcass waste (e.g. feathers, neck, head) would be disposed of at landfills but under this project, the remains will be harvested through a protein recovery. The waste will be separated, cooked, and converted into finished poultry meat meals or mixed poultry meals and valuable poultry fat, possibly for pet food, thus reducing transportation of several tonnes of biological waste to landfills. Another feature of the The Nest project is the reuse of wastewater from current operations via a water treatment system that will result in water production for other processes such as truck washing, outdoor sanitation, and crop irrigation.
- Expand experiments using animal waste combined with vegetative material to determine whether they could expand alternative energy sources. Through the Scientific Research Council (SRC), there are already 250 biogas plants in operation across the island, using animal waste in the agricultural, small manufacturing, educational and residential sectors (Government of Jamaica 2010). However, research on how to increase cultural acceptance is also needed.

Fisheries

- Explore aquatic biofuel as a possible mitigation option for greenhouse gas emissions, through the linkage of fisheries and aquaculture production.
- Explore research on the role of aquaculture in carbon sequestration. This may include integrated multitrophic aquaculture (IMTA), where molluscs and seaweeds are grown as by-products using waste from more intensive aquaculture (FAO 2021).

Chapter 5

Research priorities for the water sector

Theme 1. Climate-proofing water and sanitation infrastructure for health, livelihoods and economic development

- **Outcome 1.1:** Improved development and sustainable implementation of resilient water infrastructures to address hazards and climate change impacts
- **Outcome 1.2:** Adequate and safe water supply and sanitation needs are met and support universal access with intergenerational equity

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Theme 2. Water resources management, governance and the environment

- **Outcome 2.1:** Protection of natural resources for the sustainable use of water across the island
- **Outcome 2.2:** Efficient integration of institutional and stakeholder participation across the water sector
- **Outcome 2.3:** Strengthened financial base for future water and sanitation needs

5. Research agenda for the water sector

Water plays a central role in the operation of the island's major sectors, including agriculture, mining and quarrying, manufacturing, tourism, housing and infrastructure, sanitation and health, among others (Government of Jamaica 2015a). Uniquely referred to as the 'land of wood and water', Jamaica's access to freshwater resources typically occurs from surface and underground sources, including rivers, streams, wells and springs (Government of Jamaica 2020a). Groundwater sources contribute around 84% to the island's local water supply. They are generally recharged by predictable rainfall patterns and indirectly from rivers and streams (Climate Studies Group Mona and Planning Institute of Jamaica 2017). However, with changing climatic conditions, local water resources are expected to be greatly impacted. These include a reduction in the supply and distribution of water due to increasingly variable rainfall, prolonged drought conditions, increased evapotranspiration processes, and the contamination of groundwater resources due to saline intrusion (Climate Studies Group Mona and Planning Institute of Jamaica 2017; Government of Jamaica 2015a). Surface water sources that are replenished by rainfall will also be affected. Some of Jamaica's important surface water resources, including the Rio Cobre (the island's largest Watershed Management Unit) and the Kingston Basin, have already been experiencing reduced stream flow from declining rainfall and over-abstraction for irrigation purposes and domestic needs (Lester 2015; Climate Studies Group Mona and Planning Institute of Jamaica 2017). Water-dependent sectors are also expected to be negatively affected by the decreased water supply. Furthermore, the impacts of climate change are expected to exacerbate challenges within the island's water sector, including the high energy costs, the deterioration and malfunction of infrastructures, the management of waste and its effect on water resources, the increasing water demand in water-deficient areas, the lack of infrastructure to transfer water from northern basins to drier southern areas, as well as the adverse effects of deforestation in watersheds (Government of Jamaica 2019).

Research within the water sector has been active, including published articles and grey literature addressing some of the sector's challenges through various methodologies and technological applications. Research topics include modelling water availability for use (Rankine et al. 2015; Goyal, Madramootoo and Richards 2015; Curtis, Gamble and Popke 2014), water resource management (Mitchell 2016; Grey et al. 2014; Setegn et al. 2014), natural hazard management (Henry 2020; Mandal et al. 2016; Burgess et al. 2015; Mandal and Maharaj 2013), and the social dimensions of water (Lester and Rhiney 2018; Lester 2015), among others. Townsend, Sušnik and van der Zaag (2020) researched the vulnerability of Kingston's domestic water supply due to the impact of climate change and the role of alternative water sources. Current research at the University of the West Indies (UWI) and the Climate Studies Group Mona (CSGM), has been focusing on the impact of climate change on water availability and demand, analysis of stream flow in river channels, as well as flood risks. Research has

also incorporated modelling tools such as the Soil and Water Assessment Tool (SWAT), the Hydrologic Engineering Center-Hydrologic Modeling Systems (HEC-HMS) and the Water Evaluation and Planning (WEAP) system. The utility of these models often includes combining various parameters to examine stream flow trends and integrating future climate data to model the stream flow for catchments under different climate scenarios. For example, agricultural systems which depend on rivers for irrigation will be affected by variable rainfall and increased drought conditions. Consequently, the impact on stream flow will reduce the water available for watering farms and animals. The Water Resources Authority (2018) also conducted a feasibility study of the inter-basin water transfer from the northern Dry Harbour Mountain basin to the southern Rio Cobre and Kingston basins. Other works include examining groundwater contamination in the Kingston Basin and aquifer vulnerability. For example, the National Water Commission (NWC), and Water Resources Authority (WRA), in collaboration with the United Nations International Atomic Energy Agency (IAEA), undertook a three-year technical cooperation project, Assessment of the Kingston Hydrologic Basin, which made novel use of nuclear technologies to study and protect the country's water resources (The Jamaica Observer 2018; National Water Commission 2018).

With funding from the Inter-American Development Bank (IDB), the NWC collaborated with Miya on the Kingston and Saint Andrew (KSA) Non-Revenue Water Reduction (NRW) Co-Management Programme. As a six-year (2015-2021) co-management partnership, the programme focused on maximising the efficiency of NWC's Kingston and Saint Andrews water systems by reducing non-revenue water and building the capacity of NWC personnel. In 2019, non-revenue water was reduced from 60% to 40% and network infrastructure was improved due to better GIS data and system repairs (Miya 2021). Research has been done on the climate vulnerabilities of water supply systems that serve the Kingston Basin, as well as assessing the potential in decentralizing rainwater harvesting for non-potable uses within households. Rainwater harvesting can relieve pressure on traditional potable water sources to satisfy domestic non-potable water demand. However, the projected decline in rainfall significantly counteracts the benefits of installing rainwater harvesting structures. Since climate change will reduce the volume of water captured, research is needed on incorporating rainwater harvesting structures as part of a suite of water technologies, to safeguard urban and rural domestic water supply and storage under conditions of reduced rainfall. Considering that vulnerability is site-specific, each water demand zone will have their share of vulnerabilities which calls for research on tailored climate adaptation measures (Townsend, Sušnik, and van der Zaag 2020). As a result, a commitment to research that promotes the evidence-based implementation of intervention programmes to achieve long-term development goals has been highlighted throughout water sector national policy documents. The integral role of water in the socio-economic fabric of society calls for an even greater expansion of research within the context of changing climatic conditions and emerging innovations.

Chapter 5. Research priorities for the water

Theme 1. Climate-proofing water and sanitation infrastructure for health, livelihoods and economic development

Outcome 1.1: Improved development and sustainable implementation of resilient water infrastructures to address hazards and climate change impacts.

Outcome 1.2: Adequate and safe water supply and sanitation needs are met to support universal access and intergenerational equity.

Theme 2: Water resources management, governance and the environment

Outcome 2.1. Protection of natural resources for the sustainable use of water across the island.

Outcome 2.2. Efficient integration of institutional and stakeholder participation across the water sector.
Outcome 2.3. Strengthened financial base for future water and sanitation needs.

Figure 6. *Research themes and outcomes for the water sector*

Theme 1: Climate-proofing water and sanitation infrastructure for health, livelihoods, and economic development

The island's water sector advancement requires a critical understanding of water-society relations. The water sector plays an integral role in rural and urban landscapes. However, there have been information gaps related to water access, supply, quality and distribution. According to stakeholders interviewed and a review of sector policy documents, Jamaica lags in improving sanitation and hygiene concerns. The National Water Sector Policy and Implementation Plan (Government of Jamaica 2019) states that approximately 83% of Jamaicans have access to improved sanitation facilities. However, only 22% of the population is connected to a sewerage network.

Furthermore, even though the provision of water, sanitation and hygiene are often coupled, Jamaica has had a limited policy focus on hygiene and sanitation. The Jamaica Social Investment Fund (JSIF) has been implementing a Water, Sanitation and Hygiene (WASH) programme in rural schools across the island, engaging students, teachers, parents and ancillary staff. The programme provided training, sanitation facilities, WASH kits for the maintenance of those facilities, as well as a completed WASH Plan for each school. It has highlighted the need for the sector to increase its focus on hygiene and sanitation concerns, particularly given the global COVID-19 pandemic.

The impacts of climate change are also expected to expose a myriad of issues within the water sector and possibly expand disparities within rural and urban landscapes. One such disparity involves the

social vulnerability of households and livelihoods. According to the Statistical Institute of Jamaica and the PIOJ (2018), 45.2% of households across the island were female-headed. These households tend to possess a larger share of vulnerable persons (youth, elderly, disabled, sick), suggesting implications for the gendered utility and access to water resources. For example, women face multiple burdens in sourcing clean water for the family and carrying out domestic chores (cooking, laundry, cleaning etc.) (Government of Jamaica 2020a).

Many communities have been accustomed to frequent water supply disruptions or lock-offs that occur several days per week due to challenges with water scarcity, non-revenue water, old infrastructure and leakages (Government of Jamaica 2019; S. Lester 2015; Lester and Rhiney 2018). Service outages are also more frequent during dry spells or drought conditions (Government of Jamaica 2019). Furthermore, even though the island is considered to have one of the best water quality in the Caribbean (Hutchinson 2014), this does not equate to all individuals having access to good quality water. According to stakeholders, some families continue to access water at unimproved sources or do not have sustainable access to water. Jamaica currently uses the UN metrics and proxy indicators to measure the sector's performance in accessing safe drinking water and sanitation facilities. Approximately 92% per cent of Jamaicans have access to improved water sources (Government of Jamaica 2019). However, according to Lester and Rhiney (2018), evaluating access to water based on whether a household has water piped on its premises limits analysis, masks underlying social challenges, and may also 'mislead future intervention and research programs' aimed at improving water service provisions. This was further reiterated by the WHO/UNICEF Joint Monitoring Program (JMP), which acknowledged that water supplies that are accessible on-premises are not always available when needed or free from contamination (WHO/UNICEF 2021). Even though most Jamaicans use improved water sources accessible on-premises, only 38% use available supplies when needed.

In contrast, most Haitians (64%) have water available when needed, but very few (8%) have supplies accessible on-premises (WHO/UNICEF 2021). Current international benchmarks do not directly set clear methods or indicators to adequately measure water quality (Lester and Rhiney 2018). For example, even though individuals may initially receive good quality water, the lack of consistent and reliable water availability requires various storage methods and the quality of the water stored may have deteriorated by the time it is ready for use. Good quality water can become an unimproved resource after a few days because it is stored until the point of use (Lester 2015). Hence, research on more comprehensive methods of measuring improved water access and quality for households is required.

Water is also used for a vast array of productive and income-generating activities, including irrigated agriculture, which uses a substantial portion of ground and surface water resources, as well as tourism, manufacturing, and mining, to name but a few. Generally, the availability of water resources is highest within the island's northern basins, even though current and future water demands are

highest in southerly located basins. This is due to the island's southern side hosting a larger proportion of economic activities and urban centres (Government of Jamaica 2019). More research is required to understand the degree and scale at which alternative water sources and technological innovations for Jamaica are implemented and how these depend on the region's water resources availability, accessibility, costs, and water governance (Townsend, Sušnik, and van der Zaag 2020). Considering the challenges of the island's hilly terrain, long-term, sustainable adaptation measures for the water sector will require the integration of flexible and innovative solutions.

Carry out research on how water demand, supply, storage and quality can be managed in poor and vulnerable communities and squatter settlements over time is needed. The amount of water demand required by communities, especially those within Utility Service Areas, is not outlined in the 2019 Water Sector Policy. Nevertheless, stakeholder interviews highlighted that an estimated value of 237 litres per person per day is recommended. However, there has not been any research to support the validity of the current estimated amount of water a person receives per day. Stakeholders have therefore called for research that quantifies actual water demand rather than using estimated values. Tailoring climate change adaptation plans and intervention strategies may be challenging without this research.

Water use in squatter settlements is often characterised as non-revenue water. Consequently, squatting is also directly related to the sector's water management challenges, and is a barrier to effectively implementing climate change adaptation plans. There have been discussions around social water, where low-income individuals are provided with minimal water and sewerage services (Government of Jamaica 2019). Recently, the Ministry of Economic Growth and Job Creation has been developing a Beneficiary Identification System (BIS) which will be used to support the provision of social water and ensure that vulnerable households receive assistance to meet basic water and sanitation needs (Smith 2020; Government of Jamaica 2019).

Electricity costs make up a major part of the cost of supplying water. However, even though research on cost-efficient and energy-saving technologies exists, there is a lack of knowledge about their on-farm feasibility at the local scale. Hence, the improvement of research for these on-farm technologies is needed to reduce demand and eliminate waste. Agencies within the water sector, such as the National Irrigation Commission (NIC), have been using renewable energy sources, particularly solar energy, for sections of their facilities and infrastructure. However, though beneficial to the environment, stakeholders highlighted the high initial costs of implementing solar-powered infrastructures. For ground-mounted foundation solar structures, capital is required to procure land, fencing, and other security systems such as CCTV, etc. Additionally, the cost to design solar-powered irrigation infrastructures is based on prevailing weather and environmental conditions at the site location to mitigate possible flooding, high winds and hurricane events.

Solar-powered desalination has been adopted in Antigua and Barbuda. Likewise, Grenada has also moved to build two solar-powered reverse-osmosis desalination plants to alleviate low water supply in the dry season for residents who would otherwise depend on rainwater harvesting (Charles Jr. 2019). In 2016, the Jamaica Public Service (JPS) commissioned a desalination plant that took seawater from the Kingston Harbour. Before this initiative, each month for the past ten years, over 700,000 litres of water were drawn from a well and used in operating the diesel engines of their Rockfort Power Station 24 hours per day, seven days per week. However, the recent implementation of a desalination plant reduced 20% of the water demand from the Hunts Bay aquifer (The Gleaner 2016). Nevertheless, the need for research on the feasibility of the wider use of desalination within Jamaica, especially considering the potential of water scarcity for various economic and social activities, has been met with mixed reviews. Stakeholders from public agencies acknowledged that desalination was a last resort option, and that Jamaica had many other alternatives to consider before investing in the advancement of desalination technology. Highlighting the high energy costs and the ecological challenges associated with the discharge of the concentrated saline solution created in the desalination process, the reuse of wastewater was recommended as a climate-smart alternative option that should be prioritised. Conversely, though there was consensus on the need to improve the use of wastewater, researchers within academia have acknowledged the need to investigate the potential of solar-powered desalination in the future. Even though investment in the technology may not be a current priority, research is needed to at least examine its potential in alleviating water supply and distribution challenges in some areas, such as Kingston, St. Catherine and Clarendon, which have several wells polluted by saline intrusion.

Climate change is expected to result in greater intense rainfall and storm events. Knowledge is needed on energy-efficient technology and nature-based solutions for long-term flood mitigation, as well as to reduce peak discharge from stormwater in urban areas. For Jamaica, interventions surrounding nature-based solutions often entail a repeated cycle of implementing watershed projects and rehabilitation programmes. It is uncertain if the relevant agencies have ventured outside this approach, especially considering the lack of long-term measures to sustainably protect watersheds.

Outcome 1.1: Improved development and sustainable implementation of resilient water infrastructures that address hazards and climate change impacts

RT&D activities to address knowledge gaps

- Carry out research on how water supply, storage and quality can be managed in poor and vulnerable communities and squatter settlements. This may include research on the potential provision of subsidies to overcome barriers. Water use in squatter settlements is often characterised as non-revenue water.

- Explore innovative solutions and designs to inform possible flood control. Research may include the possible detention/retention of flood waters for safe reuse.
- Improve the integration of comprehensive risk management and multiscalar disaster risk reduction strategies throughout the sector, given the increasing frequency of extreme events. This may include studies on improved early warning systems for better reservoir and emergency operations.
- Through the use of historical data, consider modelling and/or mapping the threshold of various water infrastructures in communities and regions across the island (rural and urban) to reveal their risk tolerance, the possible level of damage/disruption, and associated costs under changing climatic conditions. Having this understanding and spatial visualisation of risk may contribute to strategies and innovations for enhancing water sector infrastructure.
- Improve knowledge of how to improve the resilience of potable water infrastructure under various future climate and water use scenarios. Higher temperatures may result in more frequent fractures in water distribution infrastructures, thus resulting in greater water leakages.
- Climate change is expected to result in greater intense rainfall and storm events. Knowledge is needed on energy-efficient technology and nature-based solutions for long-term flood mitigation, as well as to reduce peak discharge from stormwater in urban areas.

Outcome 1.2: Adequate and safe water supply and sanitation needs are met and support universal access with intergenerational equity

RT&D activities to address knowledge gaps

- Improve knowledge on climate-induced water scarcity in the vulnerable rural and urban population (women, pregnant and lactating mothers, youth, elderly, disabled, and low-income persons).
- Improve knowledge of the available opportunities for reusing treated wastewater for non-potable purposes and the barriers to its adoption. Stakeholders have highlighted this as a climate-smart option that requires further research. Generally, wastewater effluent is discharged into the sea. However, additional treatment may increase its suitability for irrigation. Furthermore, reusing treated wastewater would also provide an opportunity to redirect freshwater resources to areas that would otherwise experience deficits.
- Strengthen modelling capabilities to capture population growth concerning projected water availability/scarcity and demand. It is not only important to ensure universal access for the

present generation, but also the future. However, it is uncertain if this is being considered, especially with the nation's current drive for infrastructural development.

- Capture data on water demand for specific areas across the island. Research is needed on the water supply to various communities over time.
- Expand knowledge on providing sufficient water for achieving food security under changing climatic conditions, particularly using affordable and innovative mechanisms at the farm and community level.
- Improve knowledge on strategies to manage available water surplus in the wet seasons, to ensure adequate supply to meet water demand in the dry seasons (Townsend, Sušnik, and der Zaag 2020).
- Improve knowledge on water efficiency and optimising water use throughout the sector.
- Improve understanding of urban hydrology in various urbanizing settlements and economic zones across the island.
- Enhance knowledge on the intersection of water scarcity, water safety and human health due to varying climatic impacts. For example, increasing temperatures may give rise to more water-borne pathogens. Consequently, even though Jamaica has a 70% piped water coverage (Government of Jamaica 2019), some individuals continue to access water from unimproved sources such as rivers and springs which may host pathogens. This will also provide a broader understanding of regulations governing drinking water quality and water access within urban water management and planning, particularly regarding the vulnerability of the urban poor.
- Conduct research on how changing climatic conditions will affect the nexus of urban and rural areas' water, sanitation and hygiene. Sanitation and hygiene are inextricably linked to water and play an important role in human health. Potential contamination may occur through soakaway pits due to a lack of connection to sewer lines, the use of unimproved toilet facilities and the inability to wash hands due to lack of water. As previously mentioned, Jamaica has had a limited policy focus on hygiene and sanitation. However, climate change will threaten both potable water and sanitation services. Hence, there is a need for research exploring the social, institutional and infrastructural factors that shape local water, sanitation and hygiene concerns, particularly with climate change. Megaw et al. (2020) have developed a conceptual framework that seeks to integrate climate change adaptation (CCA) and gender and social inclusion (GSI) considerations into WASH. Possible research projects include:
    - Assessing the sustainability of WASH services under various future climate scenarios (see Howard et al. 2010 and Howard and Bartram 2009). This includes the operational functionality of services and the equitable provision of services.

- Analysing any measured effect of WASH interventions in urban and rural communities. Rigorous research is required on what works to achieve the sustained success of WASH interventions at various scales and across diverse contexts.
- Assessing the barriers and facilitators of implementing WASH interventions across local areas and settings.
- Assessing the impact of climate events (flooding, drought, hurricanes, landslides etc.) on the ability of vulnerable people (disabled, elderly, women etc.) to access WASH services.

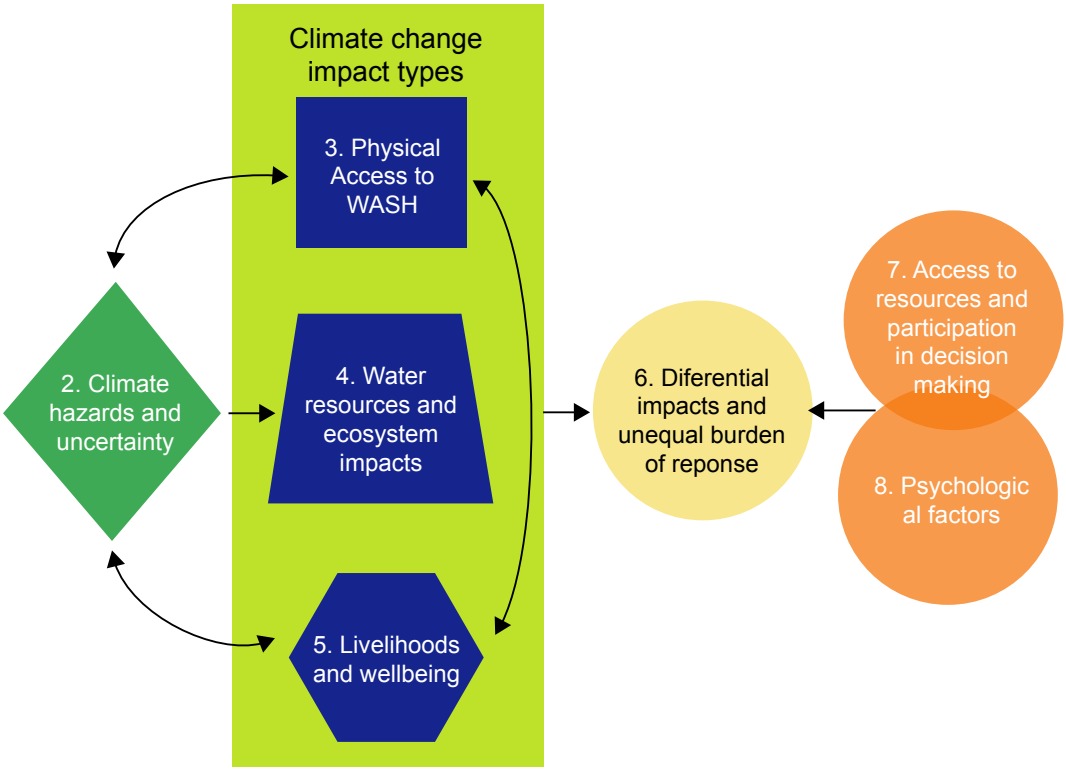


Figure 7. *A conceptual framework for integrating WASH, CCA and GSI (Megaw et al. 2020)*

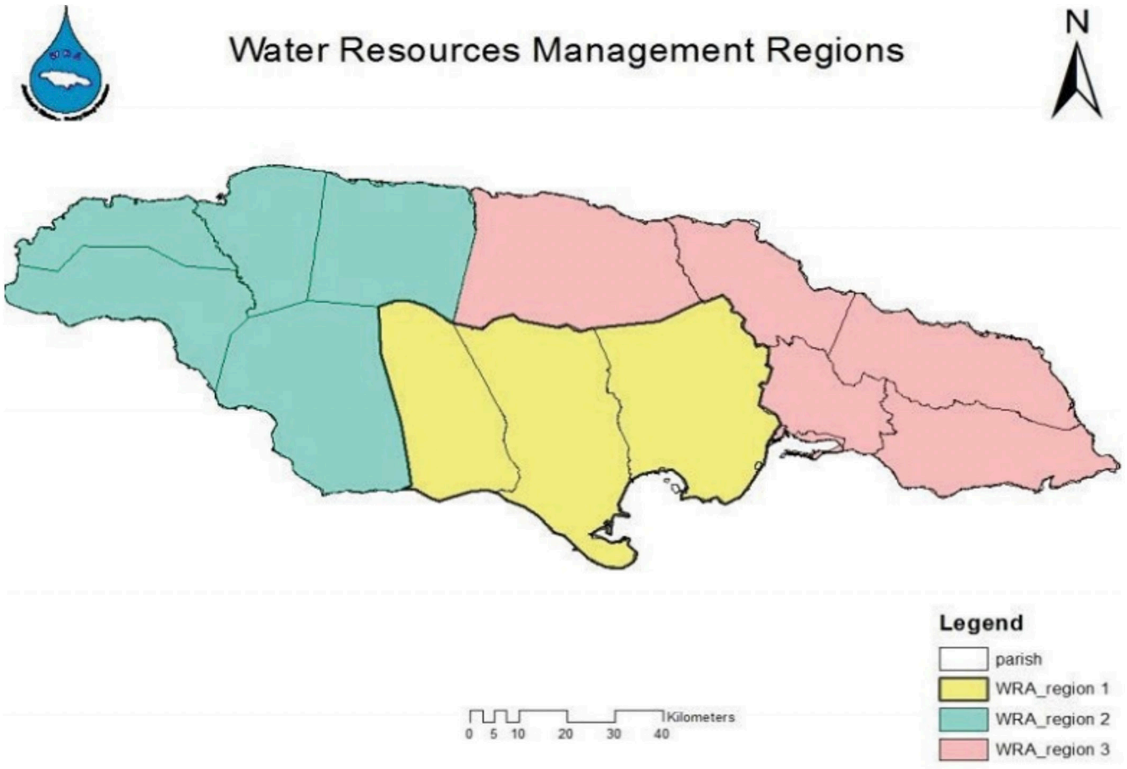
- Improve knowledge on the potential to affordably decentralise solar-powered hydro panels in other sectors across the island. This has already been implemented on the roof of the University Hospital of the West Indies in Kingston, due to the unreliability and unavailability of safe piped water for patients. This technology utilises pure condensed water from humid air, thus reducing plastic waste from water bottles and GHG emissions (Peters 2019).
- Conducting local and hydrological basin-scaled studies to assess how changes in projection scenarios of rainfall patterns will affect stream flows, groundwater availability, water quality, and water supply.

Theme 2: Water resources management, governance and the environment

Under future climate scenarios, rainfall is expected to decrease for the near-term and mid-term timescales (2030 and 2050, respectively). Seasonal rainfall patterns are also expected to shift and experience greater unpredictability, thus potentially posing a threat to water security (Townsend, Sušnik and van der Zaag 2020). It is therefore important to address the complexities associated with water resources management and the wider governance of the sector. Management of watersheds is an important facet of the narrative surrounding climate change and the sustainability of water resources. Generally, watersheds are crucial to providing drinking water, replenishing rivers and streams, and providing habitats for biodiversity. However, several of the island's watersheds have become degraded due to human activities. Of the island's 26 watershed management units, 19 have experienced increased soil erosion, siltation and turbidity, and reduced water quality (Selvaraju and FAO, 2013). Other impacts include reduced water retention capacity, decreased initial rainfall abstraction, impacted stream flows, and decreased soil permeability and infiltration rates. Under changing climatic conditions, the situation is expected to worsen, increasing water demand. Furthermore, even though the mandates of existing organisations and their relationship to national plans are broadly understood, in-depth knowledge of stakeholder engagement, including cross-sectoral collaborations with water users and community-based organisations in the decision-making process, is required. Likewise, knowledge of the financing of operations throughout the sector is under-researched.

Comprehensive data to develop catchment modelling for adaptation strategies, especially data on climate, stream flows, groundwater mapping, and water quality is lacking. According to stakeholders, even though various studies have been conducted within the sector by different individuals and agencies, there have been no long-term or continuous studies where parameters are captured to effectively examine past conditions and model future predictions. Due to a lack of sufficient data, current models often operate on a broad scale; data improvement is required to refine and downscale these models, for instance at the community level.

Associated with water scarcity, it is important to improve knowledge of potential water conflicts between communities and major economic zones. For example, the island's southern section already receives little rainfall, yet it hosts several economic activities, including mining. With projected rainfall variability and increased scarcity, water conflict issues may arise. Other potential assessments include how is the distribution and allocation of water determined, managed and governed? For example, what is being done to monitor the allocation of potable water in the agricultural sector and shortages in the domestic sector? The Rio Cobre is an agricultural water source where the National Irrigation Commission (NIC) has controlled rights. However, water has often also been redirected into



MONITORING AREAS	STREAM FLOW GAUGING STATIONS			MONITORING WELLS	ZERO FLOW MEAS.	RAIN GAUGES	FLOOD WARNING SYSTEMS	SOIL MOISTURE PROBES
	RECORDING	MANUAL	SPOT					
Region 1	10	8	21	143	16	8	4	0
Region 2	18	13	5	87	28	14	0	2
Region 3	18	7	30	56	19	9	0	0

Figure 8. *The WRA's Hydro-Meteorological Network is distributed across the island's three water management resources regions (Water Resources Authority 2018).*

the Kingston area. Hence, what are the potential conflict areas between the agricultural and domestic sectors under climate change? Improve understanding of urban hydrology in various urbanizing settlements and economic zones across the island. Considering the challenges associated with urbanisation, it is particularly important to understand future water demand, supply, distribution, and management requirements as it relates to the wider surface and underground water resources.

The Kingston Metropolitan Area (KMA) suffers from water shortages due to increased demand and reduced supply. The increase in urbanisation will lead to water shortages as well as contamination if sewage systems are not upgraded and monitored. According to stakeholders, modelling studies conducted every five years can offer insights on the impact of urban growth on water resources. This will also serve to update planning models to complement new realities under changing climatic

conditions. This means that old planning models no longer suffice for the new realities. It is important to understand the operational rules to regulate small and informal service providers, considering that increased water scarcity is one of the main challenges affecting the water sector under climate change. During drought conditions and frequent dry spells, the trucking of water to communities by the National Water Commission (NWC) has been a mainstay within the sector. Generally, truckers engaged by the NWC must follow a stringent quality assurance protocol, where their trucks are often subjected to a strict sanitary regime, including sterilisation and certification under the auspices of the Ministry of Health and Wellness. However, 'trucking' has been highlighted as an unsustainable and expensive approach to solving the water woes experienced in the sector. Furthermore, some stakeholders view this activity as an unimproved source of water, since the sanitation of trucks and the water quality often cannot be verified, especially for water trucked by informal and/or private service providers.

Research has been carried out for the Rio Minho Watershed (Henry 2020). However, more comprehensive studies are needed across the island. Currently, the Water Resources Authority (WRA) has formed a drought technical committee where drought indices will be developed to determine hydrological drought. The Meteorological Service of Jamaica uses the Climate Predictability Tool (CPT) developed by the International Research Institute for Climate and Society (IRI) for drought monitoring (Neufville 2016). Using updated rainfall and sea surface temperature data, the tool can construct a seasonal climate drought forecast model. It can also be used in tandem with the Standardised Precipitation Index (SPI) tool, developed by T.B. McKee, N.J. Doesken, and J. Kleist 1993, to monitor drought conditions based on precipitation (Meteorological Service of Jamaica 2017). The SPI can monitor conditions on various time scales ranging from one to 12 months. This temporal flexibility allows the SPI to be useful in short-term meteorological, agricultural, and long-term hydrological applications by providing early warning for the potential onset of drought and for assessing the severity of a drought (Jamaica Climate 2021). Improve knowledge on restoring natural storage systems that can enhance groundwater recharge, including the sustainable management of aquifers and nourishing wetlands. Currently, the Water Resources Authority (WRA) is involved in 'managed artificial recharge' whereby water is injected into the aquifer to remove saline intrusion. Increased variability in rainfall will lead to the variability of water resources.

Data that quantifies actual evapotranspiration from hydrological basins, as opposed to current estimates is not available. There is an opportunity to quantify projections of future evapotranspiration rates under changing climatic conditions. According to stakeholders from the Meteorological Service of Jamaica, evapotranspiration is one of several parameters collected by the 90 automatic weather stations (AWS) installed across the island. Soil moisture probes are also installed at approximately ten sites island wide. However, under the Pilot Programme for Climate Resilience (PPCR) project, there are plans to increase the density of these instruments to support research initiatives.

With groundwater being an important resource for the island, it is very difficult to examine its terrestrial operations without considering the relationship with coastal or offshore processes. This it is important to examine the links between rainfall on land, its percolation into groundwater flow patterns, and its discharge into the sea. Furthermore, since climate change will affect the interface between groundwater's outflow and saltwater inflow (saline intrusion), quantifying these flows will improve knowledge of terrestrial water supply and the quality of the coastal environment.

Outcome 2.1: Protection of natural resources for the sustainable use of water across the island

RT&D activities to address knowledge gaps

- Improve empirical research linking what is known about the likely impact of climate change at the catchment scale, while documenting the interplay of water resources, ecosystems, and human response.
- Conduct studies addressing drought at the watershed level, as this phenomenon is more localised than other events.
- Improve long-term baseline data for the sector. This includes strengthening the rain gauge network across the island to fill the current gaps in rainfall data, as well as improving mechanisms for capturing data from ungauged streams, which are streams unequipped with stream flow stations and where discharge is estimated. The WRA manages a stream flow network that has been in existence since the 1950s. However, there are gaps within this network such as the 56 spot measurement sites (ungauged points) (Water Resources Authority 2018).
- Even though the Meteorological Service of Jamaica monitors the island's weather and climate conditions through its approximately 90 automatic weather stations (AWS) and over 100 rain gauges, stakeholders acknowledged the need for improved coverage.
- Improve knowledge on the best approaches to regulate small and informal service providers without disrupting the service they often provide to the poorest and most vulnerable (WASH 2019).
- Develop consistent isotope studies to estimate recharge for all of the hydrological basins in Jamaica. According to stakeholders, the sector needs to build on the success of the completed IAEA/NWC/WRA three-year technical cooperation project Assessment of the Kingston Hydrologic Basin to avoid data gaps.
- Improve knowledge on restoring natural storage systems that can enhance groundwater recharge, including the sustainable management of aquifers and nourishing wetlands.

- Investigate how climate change will affect fresh and marine water quality. Climate change is expected to impact water quality through pollutant concentrations. Increased evaporation, as well as periodic intense rainfall events, often cause an increase in nutrients, sediments, and other pollutant loads in water bodies. These conditions and higher temperatures will lead to increased eutrophication and diseases in aquatic species (fish, mammals, coral reefs, etc.).
- Expand appropriate modelling frameworks to assess the risk of flooding, erosion, and stream health for all watersheds in Jamaica under projected land use changes.
- Undertake research to capture data on the quantity of groundwater discharged into the sea, particularly since estimates are currently being used.

Outcome 2.2: Efficient integration of institutional and stakeholder participation across the water sector

RT&D activities to address knowledge gaps

- Improve knowledge on the best approaches to regulate small and informal service providers without disrupting the service they often provide to the poorest and most vulnerable (WASH 2019).
- Improve knowledge on monitoring and evaluation mechanisms to understand the effectiveness of different interventions at improving current water supply, and sanitation needs across rural and urban landscapes. These interventions are often done through collective/collaborative action, hence, an assessment of the participation of stakeholders through inter-agency coordination on delivering these interventions efficiently is also required.
- Expand knowledge on the integration of private service providers into climate change adaptation and resilience plans for the water sector.
- Improve knowledge of perception and methods of corporate water management throughout the sector.

Outcome 2.3: Strengthened financial base for future water and sanitation needs

RT&D activities to address knowledge gaps

- Improve knowledge of the enabling and constraining factors that influence the blending of public, donor and private finance to reduce risk and increase funding for service providers. Recent reports have revealed that due to delinquent customer payments, the National Water Commission (NWC) – the main producer of more than 90% of Jamaica's total potable water supply – is facing substantial energy costs. Unpaid energy bills threaten the ability of the organisation to provide water in several areas. In addition to electricity costs, customer payments also cover costs associated with treatment chemicals, labour costs and the costs of pipelines and other infrastructure.
- Research is needed on appropriate and equitable financing methods for all stakeholders and water users. This can provide solutions and recommendations on how to systematically target, integrate and phase water resources interventions, as well as optimise improvements in water security in basins across the island.
- Improve knowledge on institutionalising financial tracking tools into programmes to improve the ability of organisations to successfully budget, monitor, and track water and sanitation financing. This is particularly integral for current and future demand in the sector and will further broaden the knowledge of the barriers to financing.
- Improve methods to affordably target, integrate and phase efficient technologies across rural and urban landscapes, including new biotechnology, drip irrigation, rainwater harvesting structures, wastewater reuse, recycling, solar panels etc., to reduce emissions.

Chapter 6.

Research priorities for the energy sector

Theme 1. Climate vulnerability modelling for Energy systems

Outcome 1.1	Understanding climate impact in the context of future scenarios and exposure for energy generation and distribution.
Outcome 1.2	Development of integrated solutions that optimise both mitigation and adaptation

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Theme 2. Energy generation (renewable sources)

Outcome 2.1	Create a partnership between the energy sector and waste management, and agriculture sector to facilitate waste to energy production
Outcome 2.2	A well-defined and established governance, institutional, legal, and regulatory framework for the diversified energy sector

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Theme 3: Energy efficiency

Outcome 3.1	Improved efficiency of generating, distributing, and utilising energy resources
Outcome 3.2	Contribute significantly to reducing medium-term and long-term GHG emissions

Chapter 6. Research priorities for the energy sector

The energy sector was responsible for over 86% of carbon dioxide emissions in 2007. The subsectors, electricity and heat generation, contributed to over 70% of Jamaica's total emissions over several years (Jones and Barrett 2020). Electricity, transportation, and the bauxite industry are the largest energy consumers. The hotel industry, tourism and the National Water Commission follow close behind as priority subsectors of concern for improved energy efficiency (Jones and Barrett 2020). In examining and defining the research and technology needs, these energy subsectors will be highlighted for either direct or integrated measures. Electricity will be subdivided into general electricity generation, electricity transmission & distribution, and renewable energy.

Jamaica has already begun its journey to resilience and economic stability by emphasizing the reduction of GHG emissions as a means of moving towards global climate change mitigation and adaptation. Locally, these decisions play key roles in the improvement and future sustainability of many of the nation's sectors. The energy sector is only one of many that have begun to reform policy towards a greener economy and climate resilience. However, since energy has links with other sectors, several comprehensive policies, plans and frameworks have already been developed through regional and global support. These governance instruments include but are not limited to:

- Jamaica's National Energy Policy 2009-2030
- Renewable Energy Policy 2010-2030
- Energy-from-Waste Policy 2010-2030
- Biofuels Policy 2010-2030
- Carbon Emissions and Trading Policy 2010-2030
- Energy Conservation and Efficiency Policy

The Climate Change Policy Framework for Jamaica pulls from these instruments for its situational analysis and supports its strategies and action plans regarding the sector. The Framework seeks to support the goals of Vision 2030 Jamaica by decreasing the inherent risk of climate change in all of Jamaica's sectors and development goals (Ministry of Water, Land, Environment and Climate Change. 2015). Even with the influx of partnerships to drive the development of the energy sector, there are still areas of inefficiencies in production and distribution as well as in the use of technologies to reduce the dependency on general electricity generation and include more renewable sources.

Jamaica's energy sector is still largely dependent on imported fossil fuels. Based on the sector technology needs assessment (TNA) and technology prioritisation report (Jones and Barrett 2020), Jamaica's energy mix now stands at 45% petroleum, 37% natural gas and 18% renewable energy, including wind and solar and hydropower. This shows progressive movement toward reducing GHG emissions in the energy sector: before Jamaica's Vision 2030 and the National Energy Policy 2009-2030, petroleum accounted for 95% of the fuel used to produce energy in Jamaica. Since the advent of policies and frameworks to reduce GHG emissions and build climate resilience, as outlined in Jamaica's first NDC, several initiatives and projects have been implemented in the energy sector (Policy Planning Development and Evaluation Division 2017). Notwithstanding this work, there is still a need to further integrate policy, research, and technology development on our way to a greener economy.

Research has shown that the power grid continues to experience frequency violations which are being addressed using Battery Energy Storage Systems (BESS). Voltage instability and power efficiency is still an ongoing issue that requires further research and technology development (Chen et al. 2020). Reduction in air conditioning costs for the tourism sector and diesel dependence for the urban transit system are all measures of energy efficiency that must be integrated into the long-term strategy for improved sustainability and energy security (WorldWatch Institute. 2013). Implementing plans that exploit energy efficiency combined with the forecasted continued reduction in the cost of some renewable technologies (IRENA - International Renewable Energy Agency 2020) creates an environment for Jamaica to achieve its energy security and sustainability goals.

Chapter 6. Research priorities for the energy sector

Theme 1: Climate vulnerability modelling for energy systems

Outcome 1.1 Understanding climate impact in the context of future scenarios and exposure for energy generation and distribution.

Outcome 1.2 Develop integrated solutions that optimise both mitigation and adaptation.

Theme 2: Energy generation (renewable sources)

Outcome 2.1 Create a partnership between the energy sector, waste management and the agriculture sector to facilitate waste-to-energy production.

Outcome 2.2 A well-defined and established governance, institutional, legal and regulatory framework for the diversified energy sector.

Theme 3: Energy efficiency

Outcome 3.1 Improve the efficiency of generating, distributing and utilising energy resources.

Outcome 3.2 Contribute significantly to reducing medium-term and long-term GHG emissions.

Figure 9. *Research themes and outcomes for the energy sector*

Theme 1: Climate vulnerability modelling for energy systems

As an island nation, our energy sector is very climate sensitive. Energy supply and distribution are impacted by an increase in temperature, sea-level rise, hurricanes, storms, and inadequate rainfall (Climate Studies Group Mona and Planning Institute of Jamaica 2017). Like several generation plants, Jamaica's distribution network runs along its coasts. This means that the impacts of climate change are a direct threat. A circular relationship exists between Jamaica's energy sector and climate change, where improvements in one benefit the other and vice versa. Although, as a SIDS nation, its contribution to global emission rates is not as significant as developed nations, there is still a sense of duty to make a targeted contribution to emission reduction.

Jamaica's projected energy demand in 2030 based on the business-as-usual model and efficiency improvement plus fuel diversification model is 9.9% and 6.5%, respectively (Ministry of Energy and Mining 2009). While potential demand is being projected and projections for the climate change variables that impact energy are known, research in adapting the energy sector for better climate resilience is limited. With the move towards greater renewable energy research, how hydro, solar, and wind energy production will be affected by temperature, rainfall, hurricanes etc., needs to be modelled. Emerging technologies such as hydrothermal energy should also be considered as the world drives toward a Blue Economy. Local scenarios inclusive of damage projection will also benefit the fight toward resilience.

Scientific research on climate projections for Jamaica and the Caribbean is known and continually improves available information. For example, Jamaica has projected a temperature increase for the 2030s and 2040s. Specifically, based on Figure 29a of the state of the climate report, every zone is projected to have no less than a 1.48°C increase and up to a 2.83°C increase by the 2030s. The upper and lower limits of temperature increases occur in the coastal zones (Climate Studies Group Mona and Planning Institute of Jamaica 2017). More recent work also points to a drying pattern in Jamaica and across the Caribbean (Climate Studies Group Mona and Planning Institute of Jamaica 2017). The direct impact of increased temperature on energy is higher inefficiencies and loss, as higher temperature reduces transmission capacity while increasing energy demand for cooling (Bartos et al. 2016). This factor, being one of many, creates a considerable issue for all energy demand and supply projections.

Outcome 1.1 Climate impact is understood in the context of future scenarios and exposure for energy generation and distribution

RT&D activities to address knowledge gaps

- Develop local climate-based models to utilise climate change projections and how these directly affect hydro, solar and wind energy generation efficiencies.
- Develop local climate-based models to utilise climate change projections and how these directly affect the efficiencies of energy transmission.
- Develop local scenarios and projections of potential future damage to the energy sector and subsectors continuously to improve decision-making and planning.
- Develop and pilot microgrid systems in rural Jamaica to assist with impacts from natural disaster and climate-based incidents and improve electricity availability efficiencies.
- Measure, monitor, and evaluate the energy systems' vulnerabilities and use localised model outputs to develop responses.

Outcome 1.2 Development of integrated solutions that optimise both mitigation and adaptation

With projections, global commitment, and local goals, the approach to achieving energy security and climate resilience will require integrated solutions. Adaptation and mitigation strategies should exist in symbiosis to achieve long-term sustainable results. For continued improvements in energy efficiency in all sectors and to develop a better understanding of the obstacles to improved efficiencies (United States National Research Council et al. 2010), research into solutions that target adaptation and mitigation is key. It is important to develop integrated approaches for evaluating energy services in a system context that accounts for a broad range of societal and environmental concerns linked to climate change (National Research Council 2012).

The tourism sector is heavily dependent on fossil fuel use for electricity generation. Still, it earns 10% of the annual GDP, provides one-quarter of Jamaican jobs, and spends up to 10% of its revenue on high electricity costs (Ochs et al., 2013). These costs are due to lighting and air conditioning. The February 2020 TNA report identified natural refrigerants as a viable option for air conditioning. The specific refrigerant, design style and type that would fit this sector and criteria still requires further research. There is also a need for proper data collection, storage and sharing to enable a better economic analysis of the sector.

The tourism sector and the housing market can positively impact Jamaica's energy efficiency by implementing improved designs for new constructions that include renewable energy products and improve the layout and orientation of the building. These changes to development standards can lead to more efficient buildings. They can be achieved by modelling best practices from the Net Zero building on the University of West Indies Mona campus. Going hand in hand with an integrated solution is the need for a resulting cross-sectorial improvement to allow for national growth and change.

RT&D activities to address knowledge gaps

- Investigate best techniques for renewable energy grid penetration, such as particle swarm optimisation (PSW), others.
- Feasibility studies on the use of natural refrigerants in the tourism sector aimed at quantifying the potential cost-savings and efficiency improvements these natural options offer by determining the most suited technological design.
- Carry out an in-depth investigation into major road networks, grid stability, positioning of charging stations, zoning of Electric Vehicle (EV) transit operations and a cost-benefit comparison of EVs and conventional vehicles to create a competitive market price alternative (Chen et al. 2020).
- Investigate using renewable energy sources to power EV charging stations as standalone units from increased renewable energy (RE) penetration to the grid.
- Modelling EV battery degradation due to vehicle to grid and the benefits of regulated charging services, daytime charging versus night charging.
- Research the benefit of transitioning up to 20% of private vehicles to hybrid and plug-in hybrids and how it would impact reduction in GHG and gasoline usage.
- Develop and implement a resource database to organise renewable energy assessments to promote investment opportunities and proper research and evaluation for proposed projects.
- Develop battery prototypes through public-private partnerships to improve the energy storage capacity of the grid and offer a new cost-effective option to small-scale solar energy users.
- Conduct feasibility studies for wider use of solar technologies such as a solar manufacturing facility and solar photovoltaic panels (PVs) for homes and rural electrification.
- Investigate how to incorporate passive and net-zero building best practices into future building projects and the basis for retrofitting existing structures to improve efficiency.

- Investigate the feasibility of redesigning or relocating sections of the whole distribution system to reduce climate impacts, and utilising grid-level battery storage systems for an emergency response to disasters.
- Conduct a feasibility study to include wind mapping for offshore sites and the viability of geothermal energy sources that would not increase sea surface temperature or affect the ecosystem.
- Develop systems to facilitate the continuous assessment of resources available for energy recovery based on current waste planning drivers and analysis of the country's waste stream.

Theme 2: Energy generation (renewable sources)

Outcome 2.1 Creation of partnership between the energy sector and the waste management and the agriculture sectors to facilitates waste to energy production

Waste management is an important area for improvement in Jamaica. The sector is managed and regulated by a single entity with several restraints. Compounding this situation is the state of Jamaica's landfills, as well as the need for regulatory reform or operations to separate and recycle waste. These current realities create an opportunity for the Jamaican government to develop and capitalise on waste-to-energy facilities. Research in the technologies and partnership between the energy sector and waste management would see this new subsector of energy becoming a useful asset in the reduction of waste as well as Jamaica's fuel dependency.

Creating partnerships between the energy sector and other key players with potential energy resources is key to diversifying Jamaica's energy matrix. Energy from waste facilities can use non-recyclable solid waste, animal, and plant waste. Extending the partnership to include waste management, agriculture, and the energy sector should provide a potential long-term sustainable source of raw material to operate energy from waste facilities. This will improve environmental conditions on land and atmospherically, since animal manure contains methane, an energy-producing, heat-trapping gas. Jamaica's bauxite and sugar industry further provides the opportunity to use biomass for energy and recycle heat energy for internal plant generating subsidies.

KT&D activities to address knowledge gaps

- Develop training and capacity building programmes to enhance local expertise and knowledge on biodiesel and energy from waste technologies, processes, and techniques.
- Investigate waste-to-energy technologies and materials, and their appropriateness in terms of the Jamaican context.
- Conduct economic assessments of waste-to-energy facilities to determine the costs and benefits of investing in the sector.
- Research to determine options available at a small scale for waste-to-energy initiatives in rural parishes and other areas.
- Develop memoranda of understanding and other collaborative agreements between key stakeholders in the energy sector and other sectors such as agriculture, solid waste management, wastewater treatment, local government, and transport to maximise the use of waste products to generate energy and to utilise the energy produced from waste.
- Design waste intake and sorting processes in collaboration with the NSWMA that will allow for reusable and recyclable materials to be transferred to the NSWMA and non-recyclable materials to be transferred to EFW facilities.

Outcome 2.2 A well-defined and established governance, institutional, legal and regulatory framework for the diversified energy sector

Mainstreaming climate change considerations in national policy, development plans and actions is essential to building capacity for successfully implementing adaptation and mitigation measures. By addressing these critical knowledge gaps in the energy sector, Jamaica would move closer to sustainable growth and climate resilience. The Government of Jamaica and Municipal Corporations all have leadership roles in addressing climate change. By joining research granting agencies, the private sector, universities, and civil society, there can be an integrated approach to achieving the climate goals. Governance sets the stage for developing new partnerships, enhancing existing ones, and fast-tracking the assimilation of research results through effective communication and knowledge sharing.

As mentioned before, several legislative and policy works have been developed to move the energy sector towards greater efficiency, energy security and reducing its carbon footprint. There remains, however, a lack of across-the-board integration of these policy actions in sectors heavily dependent on energy/fuel, such as transportation. There also has been a slow move in creating

positional and transformative governance documents to enable cross-utilisation of potential energy resources in sectors such as waste and agriculture. Importantly, some actions that can be achieved in the short term with long-term benefits include making more efficient buildings, using LED bulbs, and switching inefficient machinery for improved efficiency models.

RT&D activities to address knowledge gaps

- Research the feasibility and benefits of integrated waste-to-energy facilities on commercial farms and hatcheries.
- Conduct cost-benefit analysis for the segregation of waste management and waste regulation.
- Research the feasibility of discontinuing the discretionary approach to X-Factor measurements to improve the affordability of electricity access for customers and explore legislative and policy frameworks to restrict the transfer of inflation to the consumer.
- Undertake studies and consult with stakeholders on taxation levels for petroleum fuels (such as gasoline, diesel, kerosene, and natural gas) to institute a system designed to enhance efficiency and conservation.
- Investigate the benefit of developing an amendment to policies surrounding energy distribution to allow the operation of microgrids in rural areas.
- Research the potential for creating an agriculture/ waste-to-energy transportation sector and how it could help ensure maximum potential, production and use of energy from waste and biofuels.
- Research the implication (negative/positive) on the development of policies to ban incandescent bulbs and switch to LED or more efficient options.

Theme 3: Energy efficiency

Outcome 3.1 Improved efficiency in the generation, distribution and use of energy resources

General electricity access across Jamaica's population has increased since 2008 from 92% to 98.93% in 2018 (Ashley, Dahodwala, and Dreiling 2019). This value captures both the urban and rural population, and Jamaica is ranked 39th among its income group, based on the USAID's categorisation of electricity access metrics. Despite this access, there is still an increasing trend toward non-technical losses. Whether these losses have stronger links to behavioural issues and affordability than infrastructural integrity and accessibility needs to be researched. In addition to USAID's breakdown of

Jamaica's energy resources, it also stated that electric power transmission and distribution losses were 26.8% in 2014 compared to 23.78% in 2008 (USAID 2017). As outlined in Figure 10, Jamaica ranks 6th in its income group, which puts it 11% higher than the group average. The Office of Utility Regulation (OUR), in the 2011 renewal of JPS's all-island licence, stipulated that they needed to have an effective and appropriate loss reduction policy to deal with the power transmission and distribution losses (Jamaica Gazette 2011). A JPS commissioned study stated that there are strong links between increases in non-technical losses and increases in electricity prices, as well as an increase in violence and poverty. However, several variable specifications from the study were not public, and there could have been biases (Arbelaez and Marzolf 2011). This means studies on socio-economic drivers and policy measures to safeguard vulnerable groups are needed.

The Jamaica Public Service (JPS) has the sole rights to distribution but not electricity generation. Though technical losses are less than non-technical, the issues of grid stability, voltage and frequency fluctuations, the efficiency of the equipment being used for generation and how renewables are integrated into the system require further research. These research areas will help achieve the Vision 2030 goal of 30% renewables within the energy mix.

The National Water Commission (NWC), steward of Jamaica's water supply, requires a high energy consumption to carry out its operation. This is a key utility based on an environmental resource that could benefit from improved efficiency and energy use, thereby improving the state of the environment. Another key subsector that requires research and technological development to aid in energy efficiency is the heat-intensive bauxite industry. There have been moves to improve these processes with JAMALCO, which is now partnered with JPS and is now able to provide up to 11 megawatts of electricity for distribution to the national grid. Still, the opportunity for the industrial sector to improve remains.

In Chen et al. 2020, an outline of how to improve some of the technical challenges of the Jamaican grid and start planning for greater renewable energy penetration proposed the use of a battery energy storage system (BESS) in place of the fossil fuel-intensive spinning reserve currently being utilised by JPS (A. A. Chen et al. 2020; S. Chen et al. 2020). An economic analysis of the spinning reserves was also carried out, highlighting that the operation and maintenance cost of using the gas turbine as a fix for voltage regulation outside of normal operating hours is not economically sustainable (Arbelaez and Marzolf 2011). However, one cannot discuss improved energy efficiency without discussing conservation behaviour and the rebound effect. The rebound effect is the act of creating increased energy demand by using more efficient energy technologies. However, the nature and level of the rebound effect are one of several facets of consumer behaviour that need further investigating (Azevedo 2014), especially in developing countries where several assumptions are made, and the increase from expanded infrastructure can be misrepresented as an increase from the use of energy-efficient equipment.

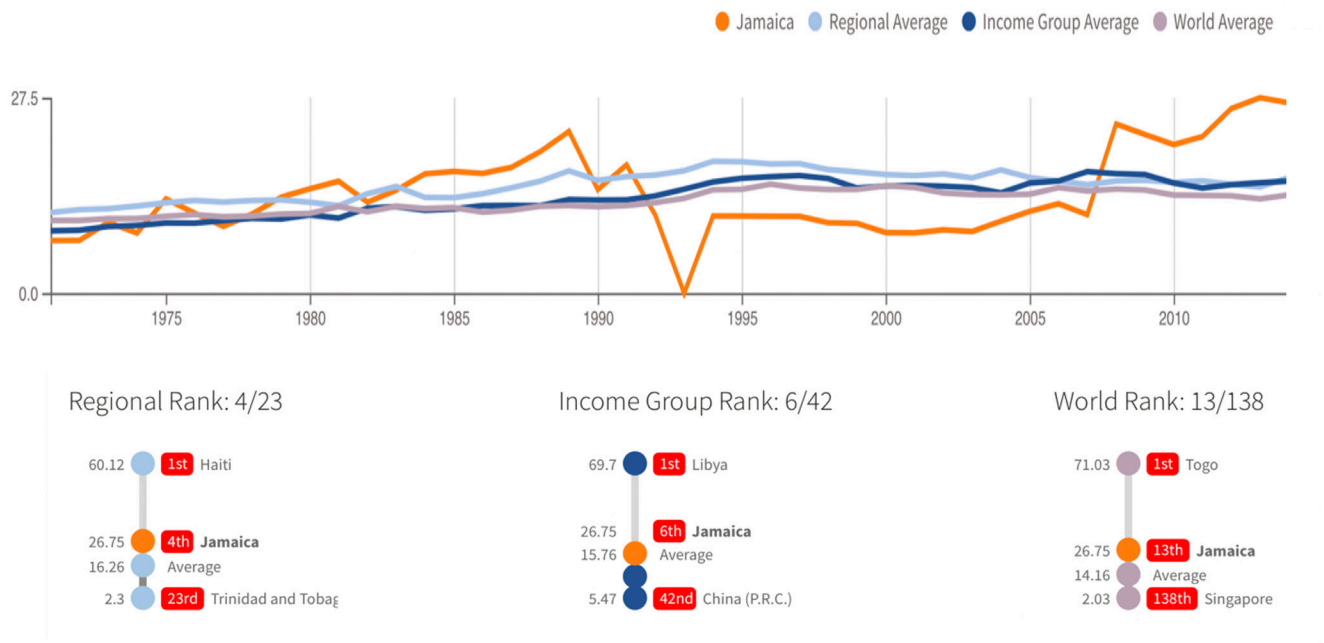

Figure 10. *Electricity transmission and distribution loss trends between 2004-2014*
Source: https://idea.usaid.gov/cd/jamaica/environment-and-global-climate-change

RT&D activities to address knowledge gaps

- Assess the impact of policies geared towards reducing distribution losses, giving attention to the welfare impact of loss-reduction interventions on low-income households.
- Investigate the links between socioeconomic drivers and effects of electricity losses to create policies that address the behavioural aspects and the social constructs that feed non-technical losses.
- Understand and model consumer behaviour to track how it impacts estimated rebound effects from improved energy efficiency measures.
- Analyse population behaviour change by introducing conservation behaviours.
- Analyse the impact of high direct grid penetration from residential or commercial renewable systems on the Jamaican grid and determine the system's potential problems.
- Conduct a comprehensive cost-benefit analysis that exceeds analysing the direct effects of losses and targets related external factors, including environmental effects and long-term performance impact on variables such as grid expansion, electricity prices, and investments (Jiménez, Serebrisky, and Mercado 2014).

- Conduct cost-benefit analysis and research on further utilising BESS to address voltage regulation.
- Research the potential use of renewable energy charging stations as a potential energy reserve for frequency regulation.
- A technical and economic study should be undertaken to determine the benefits of using solar plus battery storage and to see the benefits that can also be derived by using solar plus battery storage for peak shaving and energy substitution (Chen et al. 2020).
- Analyse the establishment and commercialisation of distributed renewable energy technologies to take advantage of local energy sources, increased security of energy supply, shorter transport distances, reduced energy transmission losses, strong community development, job creation, and income generation.
- Investigate the drivers of energy efficiency and how they affect rebound estimates.
- Identify the sources of energy demand growth, whether from the addition of first-time users or the rebound effect from introducing more efficient technology.
- Conduct feasibility studies on the use of peak flow and off-peak water distribution monitoring and control technologies to reduce the National Water Commissions energy/electricity consumption and aid in water use efficiency and conservation.

Outcome 3.2 Reducing medium-term and long-term GHG emissions

Jamaica's nationally determined contribution aims for a 25.4% (unconditional) and 28.5% (conditional) reduction of emissions compared to the business-as-usual model (Government of Jamaica 2020b). In 2015 Jamaica's fossil fuel importation was 9% of its annual GDP, approximately US$ 1.3 billion (Ashtine et al. 2018). Improvements to the energy supply mix have slightly reduced the amount of fuel imported. However, given the country's potential to use renewable resources, current fuel import levels are still too high. For Jamaica to be environmentally and economically sustainable, it needs to reduce its dependence on imported fuel, thereby reducing the amount of its GDP tied to it. Using renewable energy and waste from energy products could help Jamaica reduce its dependency.

Keeping to its global commitments, Jamaica has introduced the National Energy Policy 2009-2030 and drafted several others. Programmes such as the Energy Management and Efficiency Programme (EMEP) and the Energy Efficiency and Conservation Programme (EECP) have already been rolled out. The EECP, as of early 2020, recorded a reduction in energy consumption for government facilities ranging from 201.4 kWh to 29,490.8 kWh (Policy Planning Development and Evaluation Division 2017). This has now been a cumulative CO2 reducing activity, adding to the reduction from 2016, estimated at 2,514 tonnes of CO2 (Policy Planning Development and Evaluation Division 2017).

E-mobility is fast attracting the attention of related players in the transportation sector. There has been slow progress in reducing emissions from the transportation sector, which is one of the top three fuel consumers. The New Fortress-JUTC Liquified Natural Gas Bus Pilot Project is the most recent tangible progress towards a cleaner transportation system. Previously, other key initiatives included the use of ethanol in the gasoline mix (e.g. E10) as a substitute for methyl tertiary butyl ether (MTBE) and the introduction of ultra-low sulphur diesel (ULSD) instead of only automotive diesel oil (ADO). Studies have shown and recommended that using the electric vehicle could be a viable option for private and public transport, but extensive research is still required (Chen et al., 2020; Ashley, Dahodwala, and Dreiling 2019).

In research on the use of EVs in public and private transportation, the electricity demand is first on the radar. Electricity demand has been simulated to offset a much greater gasoline importation. A Barbados pilot study found that, with proper policy and controls, EVs may be beneficial for both the public and private sectors (Taibi and Fernandez 2017). The IRENA 2017 presentation titled '*The impact of Electric Vehicles Deployment on Production Cost in a Caribbean Island Country*' alluded to some research and policy needs that should be met to ensure this is a sustainable move. Jamaica also has a draft strategic framework for electric mobility produced by the Inter-American Development Bank (IDB). The framework includes tax and fiscal considerations, technical interoperability guidelines, measures to enhance the energy and transport sector for readiness, and measures toward developing an e-mobility ecosystem (Masson et al. 2019). Implementation measures and level of technology use still require further research to shape a transportation-energy symbiosis that benefits both public and private interests.

RT&D activities to address knowledge gaps

- Research the potential economic impact of moving from petroleum dependency to renewable and other alternative energy sources.
- Conduct a pilot study on energy conservation measures such as park and ride and incentive structures to reduce GHG emissions by reducing the distance travelled by vehicles by up to 60%.
- Research emissions from petrol vehicles and use data to create a baseline for monitoring shifts in the transport sector as EV and hybrid vehicles are incorporated for public and private use.
- Conduct a feasibility study geared towards tracking local emissions from motor vehicles to determine concentration points, thus being able to designate specific cities, towns and municipalities that could utilise the state-run park and ride facilities.

- Conduct a feasibility study about the integration of EVs in the transportation sector via vehicle to grid services and vehicle to home, and how this switch from fuel dependency to electricity dependency impacts demand and distribution of electricity, while paying attention to the utilisation of renewable energy electricity sources.
- Develop or test a system for measuring, verifying and marketing greenhouse gas (carbon dioxide) credits that will result from reducing methane generation potential.
- Research and develop battery/storage systems for renewable energy mainstreaming through partnerships between researchers and local enterprises.
- Research to understand rebound in terms of multiple metrics that include the consequences of energy efficiency interventions in energy, GHG emissions, and critical air pollutant emissions (Azevedo 2014).

Chapter 7

Research priorities for human settlements and infrastructure

Theme 1: Enhancing the adaptive capacity of the sector to climate change effects

- **Outcome 1.1:** Understanding climate change impacts on infrastructure
- **Outcome 1.2:** Developing appropriate adaptation response measures

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Theme 2: Contributing to the mitigation of climate change

- **Outcome 2.1:** Improving energy efficiency
- **Outcome 2.2:** Enhance efficient use of soil-sediment-water resources through a closing of urban material loops

7. Research priorities for human settlements and the infrastructure sector

According to the Climate Change Policy Framework for Jamaica, in 2015 approximately 82% of Jamaica's population resided along the coastline or within 5km of the coast. The country's size and topography promote the use of narrow coastal zones to develop infrastructure and population settlements. These areas include critical infrastructures such as port facilities, tourism resorts, and high-density urbanisation. Moreover, approximately 90% of the gross domestic product (GDP) is linked to the coastal areas' production (Climate Studies Group, Mona 2012).

On the other hand, climate stressors such as sea level rise increased the frequency of extreme storms. Increased temperatures can cause damage to coastal infrastructure and tourist sites, damage to human settlements, dislocation of populations, damage to power plants, power lines and substations, damage to transport and communications and damage to water supply systems (USAID 2017).

The severity and frequency of storms and hurricanes can significantly impact all areas in their path, including urban areas such as Kingston, Montego Bay, and Portmore, among others located along the coast. Sea level rise projections are from 0.18m to 0.59m by 2100 (IPCC 2007). Furthermore, Jamaica´s Second National Communications (Government of Jamaica 2011) to the UNFCCC refers to values up to 1.6m by the end of the century. Also, downscaled models show the increase of temperature by 0.82°C to 3.09°C by 2081 to 2100. In this regard, it may increase the hurricanes' intensity by the end of the 21st century (Simpson et al. 2012).

In turn, the buildings' operations and construction are responsible for almost 40% of global energy- and process-related emissions. Moreover, energy demand for buildings in 2018 was 1% higher than in 2017 and 7% higher than in 2010. In that case, to achieve the United Nations (UN) Sustainable Developments Goals (SDGs), there is a need to reverse this trend, and to decarbonise and improve energy efficiency in buildings at a rate of 3% a year (Global Alliance for Buildings and Construction, International Energy Agency and the United Nations and Environment Programme 2019). CO2 emissions from the building sector are increasing worldwide due to the demand for coal, oil, and natural gas in this sector for heating and cooking and the high levels of indirect emissions (i.e. the electricity that remains carbon-intensive). Indeed, approximately 55% of global electricity consumption is due to building operations (United Nations Environment Programme 2020).

Furthermore, the production of materials for buildings significantly impacts the environment. The use of cement, steel, aluminium, and plastic in the sector is a major contributor to GHG emissions

(Material Economics 2020). Globally, housing and infrastructure represent the largest resource footprint, with approximately 42.4 billion tonnes of resources annually, especially in the developing world (de Wit et al. 2018).

The inclusion of present and future climate change implications must be considered by developers in designing buildings and infrastructure. As a result, actions to decarbonise this sector should have a high priority, including actions on urban planning, new buildings, updating existing buildings, operations, appliances, lighting, cooking, materials, clean energy, and overall buildings' resilience. One potential option is the proposal to alter the reflectivity of surface structures (Akbari, Pomerantz, and Taha 2001; Betsill 2001). White and green rooftops and landscape adaptation not only reduce heat islands and improve air quality at the local and regional level (Taha, Douglas, and Haney 1997) but also provide other non-climate benefits such as recreational options. In addition, other options for city design and planning can also contribute to decreasing the heat effect and reducing GHG emissions produced in urban areas (Eliasson 2000; Unger 2004; Ewing et al. 2007).

Most of the proposed adaptation strategies to climate change include structural or engineering options, for instance, protection of existing infrastructure from sea level rise (National Research Council 2010). However, there are also non-infrastructural strategies (e.g. emergency response and improvement of the understanding of the social-ecological vulnerability of cities and their population) that need further attention. In this context, additional integrated and multidisciplinary research efforts and actions are needed to improve national capacity building to address climate change challenges.

Chapter 7. Research priorities for human settlement and infrastructure sector

Theme 1: Enhancing the adaptive capacity of the sector to climate change effects

Outcome 1.1: Understanding climate change impacts on infrastructure.

Outcome 1.2: Developing appropriate adaptation response measures.

Theme 2: Contributing to the mitigation of climate change impact

Outcome 2.1: Improving energy efficiency

Outcome 2.2: Enhance efficient use of soil-sediment-water resources through a closing of urban material loops.

Figure 11. *Research themes and outcomes for the human settlement and infrastructure sector*

Theme 1: Enhancing the adaptive capacity of the sector to climate change effects

Extreme events associated with climate change directly affect this sector and the country's economy. In a review of the period from 1900 to 2012, the Centre for Research on the Epidemiology of Disasters (CRED) registered that seven of the top ten disasters (persons affected) in Jamaica occurred between 1979 and 2008 and the storms and hurricanes with the highest economic damage costs occurred between 1988 and 2010 (McCalla 2012). The extreme events (11 storms, including five major hurricanes and flood and drought events) between 2001 and 2012 caused losses of approximately J$128.54 billion in Jamaica (Climate Studies Group Mona 2012). In particular, Hurricane Ivan (2004) caused a loss equivalent to J$36.9 billion (Planning Institute of Jamaica PIOJ 2004; Climate Studies Group Mona 2012), and Hurricane Sandy (2012) caused a combined loss and damage of J$9.9 billion (PIOJ 2013). The most impacted sectors included housing, health, and education, accounting for 48% of damages costs (Government of Jamaica 2015a).

The importance and vulnerability of the coastline for Jamaica are highlighted in the First National Communication to the UNFCCC (Government of Jamaica 2000). In the coastal zone, there are important infrastructures such as port facilities, airports, dense population centres, tourism infrastructure and several key industries. These are located in extremely sensitive areas to sea level rise, storms and hurricanes, which would cause beach erosion, coastal flooding, and permanent inundation in some zones.

An assessment of a semi-quantitative Index of Coastal Vulnerability (CVI) to Sea Level Rise, based on the one used by the United States Geological Survey for National Parks, identified Portmore and Long Bay, Negril as highly vulnerable areas to sea level rise (Government of Jamaica 2011). The St. James coast and St. Margaret's Bay, Portland, were identified as moderately vulnerable areas and the West End to Little Bay coast as relatively low vulnerable areas. An estimate of vulnerability to storm surges from hurricanes affecting the St. James coast and Portmore indicated that by 2050, a structure at St. James located 0.5m above sea level would suffer inundation about every two years. In the same way, a structure located 0.5m above sea level at Portmore would be affected about every 3.5 years.

Projections show that without effective adaptation measures, coastal inundation will affect infrastructure and transportation assets over the century (Monioudi et al. 2018). Due to the limitations for relocation away from vulnerable areas, research on the protection and accommodation of existing infrastructure is fundamental. While effective planning is critical, funding for adaptation strategies will require significant efforts. The estimation of the funding required just to protect Jamaica's coast

in the scenario of a 1m rise in sea level was estimated to be US$462 million (Government of Jamaica 2000) (approximately $197 per person or 19% of GNP annually). Managing impacts will also require sources of funding for rehabilitation measures.

In this context, research for widespread climate adaptation measures is required to increase vulnerable communities' resilience to climatic variability.

Outcome 1.1: Improve understanding of climate change impacts on infrastructure

RT&D activities to address knowledge gaps

- Further study on the vulnerability of housing and infrastructure to negative impacts of slow onset events (e.g. sea level rise). Gather further knowledge of who and what is affected (e.g. infrastructure, neighbourhoods, human cohorts, coupled human-environment systems, among others).
- Research on methods (e.g. modelling approaches, monitoring systems, decision support systems) for risk assessment and resilience of infrastructure in urban and peri-urban zones towards extreme weather events.
- Participatory studies with a community-based approach to evaluate the capacity and condition of infrastructure under climate variability and develop adaptation strategies.
- Research on the vulnerabilities of domestic water services infrastructure and sanitation to climate change effects and actions to reduce risk.
- Analyse the link between the effects of climate change on infrastructure and the impact on health (e.g. indoor air quality and overheating risk in dwellings and buildings).
- Evaluation of sustainability and resilience of existing buildings exposed to weather effects (e.g. material degradation, corrosion, carbonation). Study weather factors (e.g. rain and wind) and their effects on buildings and infrastructure (e.g. moisture presence, runoff, biological growth).
- Continuous research to quantify the contributions of urban areas to climate change in terms of anthropogenic GHG emissions, aerosols, ground-level air pollution, and surface reflectivity (National Research Council 2010), including the consequences imposed on surrounding areas and the effects of heat island and urban vegetation-evapotranspiration feedbacks on climate.

Outcome 1.2: Development of appropriate adaptation response measures

RT&D activities to address knowledge gaps

- Research to identify alternatives to address informal housing developments that contribute to environmental degradation, unplanned development, squatting, and occupation of unsafe areas. Further hazard mapping for the establishment of no-build zones.
- Options to increase and protect the provision of basic amenities for housing under climatic variability.
- Further research on the feasibility of new housing options and alternative materials according to the populations' needs.
- In addition to green roofing, research on using other techniques such as white roofing to reduce urban heat islands is required.
- Further development of scenario planning for the social and sustainable use of space in less exposed areas and undergoing land-use change (concerning settlements) under different Shared Socioeconomic Pathways (SSPs). This also has implications for future sectoral emissions (loss of sinks and emissions from source).
- Analyse the efficacy, sociological and socioeconomic factors, and political links related to implementing adaptation strategies (e.g. eco-design alternatives, smart growth, green roofs, and landscape architecture).
- Improve knowledge of urban governance capacity and effective decision making under uncertainty to deal with climate change. Research comparing city action plans for climate variability and the features that cause or break path dependencies, or more flexible adaptive responses.
- Analyse construction techniques, including stronger connections, low screws/nails, hurricane straps, and strong roofing materials.
- Research the appropriate location for structural engineering options against extreme storms and ocean water (seawalls, sea dikes, storm surge barriers and closure dams, groynes, among others) and sources of funding.
- Research on action plans to reduce the impact on critical infrastructure and disruption of basic public services, including health and educational infrastructure.
- Research on protection and accommodation strategies of existing infrastructure for air and seaports.

- Research on stormwater management in urban areas and flood control. A comprehensive drainage analysis is needed. Areas such as Marcus Garvey Drive, Washington Boulevard, Mandela Highway, New Kingston, and Downtown are recurrent examples of the lack of a comprehensive drainage analysis.
- Research further improvement and protection of infrastructures for electricity transmission and distribution against extreme weather events.
- Continue efforts to improve physical planning and urban design approaches to advance climate change adaptation while protecting landscapes and most valued townscapes.
- Further research on the relationship between climate change and air quality in major cities and towns of Jamaica and continue efforts to develop urban planning strategies and design alternatives that contribute to reducing air pollution.

Theme 2: Contributing to the mitigation of climate change impact

The importance of this sector for the country's development is fundamental. Human settlements and infrastructure include housing, transportation networks, communication, energy, and water. Labour productivity and investment related to this sector are continuous since they cover building time and required maintenance. From 2013 to 2018, the construction sector contributed approximately 7.2% to the goods production of Jamaica's GDP (PIOJ 2018).

However, the sector also contributes greatly to the generation of GHG emissions in the country. Urban settlements and cities influence GHG sources and sink both directly and indirectly. Most anthropogenic carbon emissions are produced in urban areas (Svirejeva-Hopkins, Schellnhuber, and Pomaz 2004; S. Chen et al. 2020). Rees and Wackernagel (2008) indicate that the primary sources of emissions globally are electricity, industrial production, transportation, and waste in urban areas (Folke et al. 1997). The carbon footprint is enlarged by energy consumption, the change in land use due to rapid urban expansion, and ecosystem impacts (National Research Council 2010; Rees and Wackernagel 2008). The construction sector plays a significant role in climate change, particularly cement manufacturing (Yokoyama 2021) and other building materials, energy consumption for processing resources, equipment operations, and the disposal of construction waste (Rees and Wackernagel 2008). The construction and functioning of buildings, roads, and other infrastructure, combined with other carbon dioxide, pollutants and heat emissions, exacerbate profound surface and atmospheric changes (Landsberg 1982; Oke 1997). In particular, construction and demolition waste (e.g. concrete, metals, wood, plastics, asphalt, cardboard) harm the environment, economy, and society (Yahya and Halim Boussabaine 2006).

The Biennial Update Report of Jamaica (Mahlung and Dore 2016) estimates the country's total emissions between 12 and 14 million metric tonnes of carbon dioxide equivalent between 2008 and 2012. The sectors with the highest emissions include agriculture, electricity generation, bauxite and alumina production, and transportation. Furthermore, the Climate Change Mitigation Consultancy prepared by the Stockholm Environment Institute (SEI) (Stockholm Environment Institute 2017) showed updated national estimations of GHG emissions by sector: agriculture 34%, electricity generation 21%, road transport 14%, and bauxite and alumina production 12%. The closure of a few alumina refining facilities (Windalco and Alpart) between 2008 and 2009 resulted in a drop of almost 20% in national emissions. Cement manufacture is also a highly energy-intensive production process. The Caribbean Cement Company uses coal and fuel oil as the main energy sources to manufacture cement and, in addition to auto-generation, purchases electricity from the Jamaica Public Service Company (Mahlung and Dore 2016). In this regard, the third National Communication of Jamaica to the UNFCCC included estimations of the CO2 emissions from cement and lime production. These estimations hovered between 413,666 Mg CO2 and 542,017 Mg CO2 between 2006 and 2012.

In 2015, Jamaica submitted its Intended Nationally Determined Contribution (INDC) (Government of Jamaica 2015b) to the UNFCCC. The country committed to mitigating the equivalent of 1.1 million metric tons of carbon dioxide per year by 2030 compared to the 'business-as-usual' (BAU) scenario of emissions growth without policy intervention. This is equivalent to a reduction of 7.8% of emissions compared to the BAU scenario, or 10% below the BAU scenario, subject to the provision of international support to improve the implementation of its 2009-2030 National Energy Policy.

Although Jamaica has low levels of greenhouse gas (GHG) emissions compared with other countries, the country's goal is to contribute to substantial reductions for mitigating the effects of climate change. In this regard, the human settlements and infrastructure sector is key to this effort. Research that faces urban centres' growing requirements (Cashman 2014) and contributes to reducing the sector's climate footprint, as well as the adjustment and implementation of previous research findings from other regions, especially in the Caribbean communities, are essential.

Outcome 2.1: Improved energy efficiency

RT&D activities to address knowledge gaps

- Evaluation of design strategies for thermal comfort and energy consumption under climate scenarios. The development of housing types and construction techniques for energy conserving and energy efficient housing designs, including active and passive adaptation measures that improve thermal comfort (e.g. cool painting and white roofing, solar screens, evaporative cooling, ventilation, among others). Further research to identify alternatives to reduce energy demand by buildings and decrease the urban heat island.

- Research, evaluation, implementation and monitoring of clean cooking alternatives in houses.
- Research on options to displace electric and liquefied petroleum gas (LPG) water heating to implement solar water heaters in newly constructed and existing houses.
- Analyse the development and implementation of tools for measuring energy performance and management in building operations. Study energy demand and consumption, including estimation methods in energy consumption (electricity consumption, cooling energy requirements, heating, costs, and financial implications).
- Research on options to decrease costs and promote residential and public/commercial LED or fluorescent lighting to reduce electricity demand and related emissions due to electricity production.
- Analyse the development of decarbonisation strategies for refurbishment and retrofitting of existing buildings. Assess retrofitting measures and new designs to achieve net zero emissions or net zero energy.
- Further research on the environmental effects of implementing reflective and green roof mitigation technologies and on the impact of greening on energy savings. Study the use of different vegetation, plant morphology and physiology, and substrate, among others.
- Conduct a cost-benefit analysis of ecological design implementation and carbon footprint analysis of materials for environmentally friendly buildings and infrastructure.

Outcome 2.2: More efficient use of soil-sediment-water resources through a closing of urban material loops

RT&D activities to address knowledge gaps

- Analyse the quantification of the impact of major potential sources of pollution from construction processes (e.g. waste materials, contaminants in the atmosphere, emissions from construction vehicles and equipment) and assess GHG emissions associated with different infrastructure types and construction operations. Further knowledge of the life cycle of GHG emissions generated on the construction sector.
- Alternative technologies for material production and management (e.g. CHP for alumina production, switch from fuel oil to LNG) are targeted for construction. Research strategies for promoting low carbon materials in construction and continue efforts to improve new construction materials and selection of building products to decrease the carbon footprint.

- Further research on construction and demolition waste tracing and quantity and quality estimation. Research on options for waste reduction and disposal to reduce pollution from construction activities. Improvement of reuse and recycling processes, and the development of efficient strategies for construction and demolition waste management to reduce related carbon emissions and decrease the rate of non-renewables depletion.

Chapter 8

Research priorities for the waste sector

Theme 1: Reduction of emissions from the waste

Outcome 1.1	Innovation in product design to use fewer resources and reduce waste
Outcome 1.2	Sustainable consumption patterns promoted to reduce waste generation
Outcome 1.3.	Reduction in emissions from solid waste disposal
Outcome 1.4.	Strengthening the pathway for waste to energy production

8. Research priorities for waste

In Jamaica, the framework for solid waste management is composed of the National Solid Waste Management Act (MOJ 2001), the Public Cleansing Regulations, the Public Health Act of the Ministry of Health and the Trade Act, which regulates the scrap metal industry (recycling initiatives) (Riquelme, Méndez, and Smith 2016).

The National Solid Waste Management Authority (NSWMA) is the statutory body established in 2002 under the NSWM Act (MOJ 2001; National Solid Waste Management Authority 2019). The NSWM Act recognises the dual role of the NSWMA in regulating and managing Jamaica's solid waste sector. The NSWMA efforts have focused on managing solid waste and regulating public behaviour, having an enforcement unit leading the process. The functions of the NSWMA are implemented via four limited liability waste management companies: WPM Waste Management Limited, MPM Waste Management Limited, NEPM Waste Management Limited, and SPM Waste Management Limited. These companies were established in the 1980s. Since 2002, the NSWMPA has overseen them, assuring the provision of waste collection services to over 70% of Jamaica's population (National Solid Waste Management Authority 2019; MOJ 2001).

The law establishes that the NSWMA mandate is to protect the health and safety of the nation through the effective management of solid waste. This is done by collecting residential and commercial solid waste, enforcing the NSWMA Act and managing eight disposal sites (National Solid Waste Management Authority 2019; MOJ 2001). Some waste material is sent for anaerobic digestion, but most is sent to disposal sites. There is increasing pressure on these waste management processes due to population growth and increases in the waste generated per capita (Ministry of Economic Growth & Job Creation, Climate Change Division et al. 2018). The NSWMA is mandated to manage all disposal sites until divestment occurs. Up to 2019, there were eight disposal sites under management located in Portland, St. Ann (two), Kingston & St. Andrew, St. Thomas, St James, St Elizabeth, and Manchester (National Solid Waste Management Authority 2019).

Urbanised areas are increasingly important to climate change (National Research Council 2010). Unsustainable environmental management practices increase the population's vulnerability (PIOJ 2018), and communities use gullies and waterways as dumping sites, blocking drainages that increase flood risks. In the agricultural sector, slash and burn practices are implemented, reducing plant cover on hillsides, increasing the likelihood of landslides, poor waste management, contamination of water resources and finally, poor disposal of collected water that leads to the proliferation of vector-borne diseases.

According to Ochs et al. (2013), Jamaica generates about 1.5 million tons of waste annually, of which 55% is collected by garbage trucks, and 69% consists of organic matter, causing high amounts of methane due to its high organic matter and moisture content. The Planning Institute of Jamaica estimates that the country's Municipal Solid Waste (MSW) generation will increase to 2.4 million tons by 2030. However, effective waste management programs could lower this to 1.8 million tons (Ochs et al. 2013). Direct combustion for waste-to-energy was evaluated, but efficient burning is not possible due to the high level of organic waste due to high moisture content.

Emissions from landfills are the third-largest component of CH4 emissions (with a higher global warming potential than CO2) (Global Methane Initiative 2011) and result from the breakdown of organic waste under anaerobic conditions. CH4 emissions from waste that is landfilled in a specific year occur over a long period. Thus, the emissions in any given year represent the sum of emission contributions from waste that has been landfilled across many years (Ministry of Economic Growth & Job Creation, Climate Change Division et al. 2018). As the Third National Communication (2018) identifies, emissions from other sources in the waste sector include industrial and domestic wastewater treatments, small emissions from anaerobic digestion and waste burning (open burning and waste incineration) (Ministry of Economic Growth & Job Creation, Climate Change Division et al. 2018; Haro et al. 2019).

Table 3 shows the use of the framework proposed by Alpizar et al. (2020), referencing indicators for defining policy goals to reduce marine plastic pollution in Jamaica. The indicators show that of the total plastic waste, 27% is inadequately managed, and from the 73% that is properly managed, only 9.5% is being recycled.

Table 3. *Reference indicators to define policy goals to reduce plastic pollution in Jamaica*

	Production	**Consumption**	**Disposal**			
	Balance of trade for the plastic industry*	Plastic consumption per capita (kg/person/day) [a]	Share of plastic inadequately managed (%) [a]	Share of wastewater treated (%)	Share of waste collected legally (%)	Share of plastic that is recycled (%)
Jamaica	Deficit	0.03	27	69%	76.8[c]	9.5
World average		0.20	36	26	64[d]	19.5 [a]
Top 10 countries		*0.16*	*0.85*	*87.5*[e]	*97* [f]	*46.3*

Notes: * Country data for 2018. Trade Balance (TB) = Total Value of Exports –Total Value of Imports; surplus if TB>0; deficit if TB<0. Sources: [a] Jambeck et al. (2015) [b](Silva 2015) [c]NSWMA Annual Report 2018/2019, [d] Lower-middle income countries average 64% (Kaza et al. 2018), [e] OECD (2019), [f] Kaza et al (2018) and framework adapted from Alpizar et al (2019)

NEPA is the entity in charge of monitoring sewage treatment plants (STP). In 2013, there were 234 STPs. A total of 73 STPs were under the management of the National Water Commission (NWC), the

statutory body responsible for providing water supply and wastewater services to most of the population of Jamaica. The remaining STP are owned and/or operated by the hotel sector, other government agencies, hospitals, private companies, and public housing development agencies (Ministry of Economic Growth and Job Creation 2018; NEPA 2019).

Chapter 8. Research priorities for waste

Theme 1: Reduction of emissions from the waste sector

Outcome 1.1 Innovation in product design to use fewer resources and reduce waste.

Outcome 1.2 Sustainable consumption patterns promoted to reduce waste generation.

Outcome 1.3. Reduction in emissions from solid waste disposal.

Outcome 1.4. Strengthening the pathway for waste to energy production.

Figure 12. *Research themes and outcomes for the waste sector*

Theme 1: Reduction of emissions from the waste sector

About 79% of households use public or private garbage collection, and about 21% of the population dispose of their garbage by burning it. Burning waste represents a major challenge since it not only contributes to climate change but has public health consequences as it releases harmful particulates and chemicals into the atmosphere, resulting in respiratory problems. In this section, the research gaps focus on the required knowledge to reduce emissions from the waste sector. GHG emissions from solid waste are reduced by product innovation, changes in consumption patterns through the impact pathway (producers, manufacturers, and consumers) (Alpizar et al. 2020). They are also reduced by an increased recovery of valuable materials, causing a reduction in the amount of waste disposed of in the landfill, and by improving waste collection and disposal systems (Ellen MacArthur Foundation 2019).

Outcome 1.1 Innovation in product design to use fewer resources and reduce waste

RT&D activities to address knowledge gaps

- Research to determine the enabling factors for innovation in Jamaica, particularly with the development of new products aiming at extending the product's lifespan within the economy.

- Perform life cycle analysis on new products to gain trust from customers, identifying the total environmental burden of product/packaging and trade-offs.
- Research on the overall net benefits of 'greener products', exploring rebound effects because of changes in consumption patterns.
- Welfare analysis of the introduction of greener products.
- What is the most appropriate combination of policies to foster the establishment of an in-country market for greener products? Which are the attributes that consumers value most in a product.
- What are the factors that facilitate innovation in the industry? Research into safe design, production, and use of practices and associated recycling, reuse, and remanufacturing initiatives that enhance the sustainability of development projects.
- Revision of importation policies to minimise the importation of single use/disposable/non-biodegradable items, and items with excessive/unnecessary packaging. Imported packaging is a significant source of solid waste.

Outcome 1.2 Sustainable consumption patterns promoted to reduce waste generation

RT&D activities to address knowledge gaps

The knowledge gaps identified by stakeholders are aligned with those proposed by Wikström et al. (2019), particularly relating to packaging strategies.)

- Research on the identification of incentives (regulatory, behavioural, market-based, price-based) to reduce food loss and waste at different levels (e.g. household, commerce).
- Analyse and develop environmental assessment methods that acknowledge the packaging functions that help save food, including user behaviour.
- The impact of the food packaging system, both direct and indirect aspects, including food waste, should be assessed.
- Research to understand how the various packaging functions and user behaviour affect food waste along the value chain. The analysis should include responses from different types of households and different food products.
- Explore business models to reduce food loss and waste (FLW) that are attractive for stakeholders and consumers.

- Assess the results-based financing for solid waste management. Analyse the successful implementation of this financing in Jamaica to determine how much waste management will improve.

Outcome 1.3. Reduction in emissions from solid waste disposal

RT&D activities to address knowledge gaps

- Assess the ecological and economic implications for improper waste disposal in major coastal wetland cover in Jamaica.
- Conduct a feasibility analysis at established industrial disposal sites to improve data quality and availability, and define strategies to improve environmental performance.
- Conduct an environmental impact assessment of the Riverton City Dump, which receives over 60% of the nationally collected solid waste. This is a site that is without an impermeable-lined base layer, without surface covering and without frequent compaction of waste.
- Research on the Riverton dump site and other waste disposal sites on the use of installation of landfill gas extraction pipes and flaring of the gas.
- Research on how emissions from combustible fractions differ per category of waste.
- Research on a strategy for the management of all hazardous waste contaminated sites. Particularly, red mud disposal sites, where all active red mud disposals are to be regulated.
- Assess effective strategies to clean-up select priority hazardous wastes contaminated sites to minimise the risk to human health, the environment, and the economy.
- Identify impacts of PV technology, particularly considering current waste collection mechanisms.
- Research on adopting different international models in urban planning, rural development and regional development will be beneficial for improving the recovery of valuable waste materials.
- Research on the social norms driving waste disposal. Is there a social norm for waste separation? Are there regional variations?
- Research on what attributes the collection system should have to promote waste separation, and the willingness to pay for the additional services.
- Research on household attitudes and behaviours regarding waste management? Are there differences in terms of socioeconomic characteristics or is it more related with urban planning?
- At the sectoral level, research on the residential, commercial, or industrial sectors attitudes and behaviours regarding waste management.

- Research on what policies can be effective for changing attitudes towards improved waste management systems.
- Research on enabling factors for an Integrated Waste Management (IWM) PPP concession.

Outcome 1.4. Strengthening the pathway for waste to energy production

The PIOJ (2018) indicates that innovation in biogas production from waste, such as the biodigester created by the Scientific Research Council and the College of Agriculture, Science and Education (CASE), is already being implemented in Jamaica. For instance, in 2016, 350 biodigesters for animal waste and 200 biodigester septic tanks for domestic sewage were registered, each producing 10,000 and 2,000 cubic meters of biogas, respectively (Riquelme, Méndez, and Smith, 2016). Significant quantities of methane are also produced because of the high organic content in the waste stream. As Riquelme, Méndez, and Smith (2016) highlighted, dairy and pig farms generate electricity using biogas plants and fertilisers from their organic waste.

RT&D activities to address knowledge gapss

Knowledge gaps identified by stakeholders are aligned with the sustainable energy road map presented by Ochs et al., in 2013. Specific research gaps were identified in the report and are outlined here:

- A detailed assessment to determine the true potential of biogas waste-to-energy for Jamaica.
- Assessment of the volume, characteristics, and cost of accessing waste fuel as a crucial input for the development of a waste-to-energy development plan.
- Determine which waste-to-energy systems to develop in Jamaica's major landfills.
- Assess the health and environmental impacts of direct incineration.
- Model the potential for cultivating crops in particular locations, looking at environmental variables such as annual rainfall, soil nutrient levels, and average temperatures, as well as variables like land availability and economic costs.
- Assessment of energy generation potential of municipal solid waste, considering municipalities where waste collection is efficient but storage for biomass is limited.
- Feasibility studies to identify alternatives to overcome logistical barriers to developing biomass as an energy source. Dispersed biomass residues increase the cost of collection.
- Applied research to investigate the appropriateness for agricultural application of biosolids.
- Assessment of the potential to produce biodiesel from cooking oil.
- Assessment of different strategies to enhance production of biogas using animal waste.
- Research on the determining factors that influence farmers' decision to adopt biodigesters.
- Assessment of effective market-based, regulatory, price and behavioural instruments to increase adoption of biodigesters.

Chapter 9

Enabling conditions to implement the Climate Change Research Agenda

Chapter 9 Enabling conditions to implement the research agenda

The effective implementation of the research areas identified for priority sectors requires an enabling environment that facilitates cross-sectoral collaborations, financing mechanisms, the translation of research into policies and development plans, the equitable access to and dissemination of research results, and avenues for the efficient uptake and transfer of technology. Policy goals informed by evidenced-based research require the partnership of actors, including public and private organisations, financial institutions, NGOs, research bodies, and community-based organisations.

The Climate Change Advisory Committee and the Climate Change Division in the Ministry of Water, Land, Environment and Climate Change and the Local government (Municipalities) are the designated arms of the government to steer the National Development Plan Vision 2030's climate change sustainability goals. The Climate Change Division provides mechanisms to encourage knowledge exchange and broker stakeholder partnerships to support the activities needed to address the identified knowledge gaps. Establishing a governance strategy involving the cooperation and collaboration of all stakeholders is key. This considers the participation and collaboration of multiple institutions responsible for addressing natural resources, commodities, socioeconomic, climatic, and cultural issues, and the voices of individuals who operate in these spaces at the local scale. This facilitates the flow of information and analysis at multiple scales, mends fragmented decision-making structures, expands learning opportunities, and encourages the practical application of research for development.

Agriculture

To meet the research and development gaps currently outlined for the agriculture sector, the following conditions should be met:

- The development of several policy-based initiatives. Firstly, it is important to restructure the sector's land tenure policy to ensure that farmers' capacity is not restricted, particularly with implementing climate-smart adaptation strategies and technologies, as well as accessing funding from microcredit institutions and grants to implement land management strategies. Secondly, the development of a National Fisheries and Aquaculture Policy could facilitate the broad-based implementation of climate change mitigation and adaptation strategies. Thirdly, policy guidance on the structure of urban agriculture and how individuals should operate is required.

- Incorporate a multidisciplinary approach to research where academia and sector stakeholders, including those at the grassroots level, can engage collaboratively to address knowledge gaps and facilitate the sustainability of climate-smart interventions.
- Promote innovation through the provision of incentives for public-private partnerships to address key problems and opportunities and ensure that research results are utilised by stakeholders and translate into tangible benefits for society.
- Update land use and agroecological maps. This will aid research projects and contribute to more comprehensive adaptation and/or mitigation plans and decision-making for the sector.
- Promote the creation of farmers' associations to improve their participation in the innovation process, technology and farm inputs acquisition and fair market access.
- Facilitate farmers' access to the internet to effectively disseminate climate information, market prices, and climate-smart technologies.
- Actively involve farmers in participatory on-farm research.
- Engage rural youth in the farm innovation process.

Water

To meet the research and development gaps currently outlined for the water sector, the following conditions should be met:

- Replace and/or repair lost or damaged monitoring equipment, expand the network of rainfall and stream flow gauges, and implement additional sensor equipment to capture more specific climate data such as temperature and wind.
- Cross-sectoral collaboration to monitor the implementation mechanism and capture quantifiable measurements of progress towards achieving IWRM.
- Strategic partnership across sectors (e.g. water, agriculture, health, infrastructure and settlement etc.) to aid in monitoring the progress of WASH activities.

Energy

To meet the research and development gaps currently outlined for the energy sector, the following conditions should be met:

- The strategic partnership between the agriculture, waste, transportation and energy sectors facilitates a functioning ecosystem from which to develop and sustain waste from energy production.

- Research-driven innovation leverages the University of the West Indies and the University of Technology's research capacity to support public-private partnerships towards the design and/or implementation of energy technologies.
- A hybrid approach to emission reductions focuses on creating an electric mobility ecosystem, maximising the efficient use of existing combustion engine vehicles and bridging the gap through behaviour and cultural changes.

Human Settlement and Infrastructure

To meet the research and development gaps currently outlined for the human settlement and infrastructure sector, the following conditions should be met:

- Updated land use zoning maps considering new climate impact data and projections to drive building, transportation and energy systems decisions.
- Improved frequency and extent of hazard and vulnerability mapping to feed the update of land use zonal maps, clearly designating no-build zones.
- Further improvements to the building codes and regulations to drive the use of building design and materials that support climate-resilient infrastructure.

Waste

To meet the research and development gaps currently outlined for the waste sector, the following conditions should be met:

- Collaborative research efforts between waste, energy and agriculture to improve energy access and efficiency.
- Restructuring the waste management and regulatory system to allow for a separation in roles that fosters the enhanced viability of energy from waste products.
- Infrastructure and policy position to operate via a circular economy, encouraging manufacturers to offer alternate product packaging or take back schemes and consumers recycling or up cycling products.

Implementation of the three-year plan of the National Science, Technology, and Innovation Policy: Catalysing National Development 2019-2029

Implementation of the three-year plan of the ST&I policy (MSET 2019) will promote the implementation of the research and technology development agenda since it has defined the following priority areas: agriculture, health management, waste management, education and training, crime and public safety, and funding. It thus provides an overlap between the two documents regarding agriculture, waste management and funding opportunities/mechanisms.

Among the key activities that support the R&TD agenda are:

- Develop mechanisms and tools to ensure that ST&I are mainstreamed into all developmental planning processes and governance structures.
- Integrate S&T to ensure efficient and impactful delivery of public goods such as education, health care, waste disposal, and security.
- Repair, refurbish, re-equip, and rationalise existing laboratory facilities ensuring efficient, effective, collaborative, and coordinated use across sectors.
- Develop national standards/codes of operation for all national/training infrastructures to ensure facilities are safe and conducive to learning and innovation.
- Encourage private sector involvement in developing ST&I infrastructures through public-private partnerships (PPPs).
- Develop agenda to amend, establish and rationalise legislation required for successful implementation of the National ST&I Policy.
- Conduct comprehensive legislative and regulatory reviews governing all agencies and institutions within innovation systems.
- Engage with MICAF to repeal and replace the Patent Act and Designs Act to increase the number of patents registered.
- Promote training and communication campaigns to create awareness among stakeholders of the need to adopt sustainable practices and engage them in finding solutions.

Financing Research and Development

Successfully executing the research and technology development agenda depends on the financing mechanisms in place. However, even though public agencies are mandated to conduct research, these agencies do not receive an allocated budget for research and development. Instead, research is supported by grant applications to external funding organisations. Hence, state R&D agencies are often limited to executing the mandate of the funder based on the stipulations in place for receiving financing. These stipulations for financial support are also often linked to the advancement of the funder's interests, such as providing information that would complement their programs and not necessarily for advancing the development targets of the island.

Similarly, universities are eager to pilot research for development. However, research is most commonly driven by the source of funding rather than the policy need, which often lacks the financial resources to pursue the research project (UN 2019). According to stakeholders, for Jamaica to benefit from research, the state must ensure that institutions know the knowledge needed for development, the financial aid available to facilitate the research process, and the monitoring and evaluation mechanisms to guarantee accountability. Otherwise, academic institutions and public R&D agencies will continue to execute research in line with external funding bodies. Perhaps universities could provide more research support to agencies if the government-mandated collaboration provided funding for university infrastructure, lab equipment, etc. This is a feasible measure to implement since the three-year plan of the ST&I policy points to upgrading and updating existing laboratories and research facilities. The Government of Jamaica could also share areas where research is needed, support participatory approaches to involve local communities, and sponsor students pursuing higher education to conduct research in those needed areas.

The successful advancement of research and development requires strengthening the financial base of all sectors. Therefore, the state must be decisive in its investment and financing strategies, primarily by establishing a budgeted national research and development fund that would encourage public-private collaboration to address key priorities and develop innovations. Recommendations from stakeholders for financing this fund included implementing an organised process that requires manufacturers and private sector operators to provide a percentage towards R&D commitments. There is currently an Environmental Protection Levy on sales by local manufacturers and imports. However, it is uncertain if these funds are invested in cross-sectoral R&D programs.

Finally, according to the 2020 Global Innovation Index, the island currently ranks 72 among 131 economies (Cornell University, INSEAD, and WIPO 2020). In benchmarking Jamaica against other upper-middle income economies and the Latin America and the Caribbean (LAC) region, the island

scored below average for human capital and research, infrastructure, market sophistication and knowledge and technology outputs. Regarding human capital and research, the island had an overall ranking of 88 (with 59 for education, 97 for tertiary education, and 121 for research and development). Even though Jamaica possesses an active research community, stakeholders have acknowledged a lack of substantial investment in improving the competence of human resource personnel within the public sector to mainstream climate change research and intervention plans. Therefore, decision makers need support to funnel the requisite resources into Jamaica's human capital development. Financing research and development also depends on supporting local researchers, scientists and stakeholders in areas that can advance meaningful change and result in greater resilience.

Over the period 2012 to 2018, the USAID Jamaica Mission has consistently been one of the main external funders for implementing climate change adaptation and mitigation initiatives across sectors. These have included mainstreaming climate resilience, improving climate information, promoting low emission energy systems, piloting and disseminating disaster risk-reducing (DRR) management practices, accelerating advanced energy development through renewable sources, and mobilising climate-related financing (Ashley, Dahodwala, and Dreiling 2019). Interestingly, the discussion on the enabling environment for Jamaica's Climate Change Research Agenda is comparable to USAID's analysis of lessons learned from its implementation of various climate projects and programmes. Lessons learned include:

- A research and development-first approach facilitates programming and helps countries achieve self-reliance.
- Extensive institutional and community capacity building facilitates lasting impact at national and local levels.
- Engaging youth spurs innovation and empowers future generations.
- A holistic value chain approach to resilience in agriculture facilitates local adoption of risk-reducing practices.
- Addressing climate risks in crime prevention and the rule of law programming allows mutual reinforcement between increased social cohesion and reduced risk.
- Building resilience requires longer-term investments and cohesion among sequential projects.
- National modelling for advanced energy activities can improve data collection and sharing.
- There are opportunities to further integrate climate resilience and DRR into national frameworks and processes
- Leveraging partnerships is key to overcoming challenges in national planning processes (Ashley, Dahodwala and Dreiling 2019).

USAID's Technical Report also made recommendations that complement and align with the knowledge gaps proposed in this research agenda. These include:

- Enhance short- and long-term decision support for agriculture, water, and other sectors by developing targeted, actionable climate services for key users.
- Harness Jamaica's established forecasting capacity to inform an early warning and action response system in the agriculture sector.
- Integrate climate information into DRR work at national and local levels for rapid- and slow-onset disasters.
- Land tenure as a DRR strategy increases household investment, community-level climate resilience, and equitable disaster recovery efforts.
- Provide technical assistance toward targeted interventions that strengthen the energy sector, focusing on energy efficiency and meeting the country's renewable energy generation commitments (Ashley, Dahodwala and Dreiling 2019).

Climate change is already occurring across the island, impacting the social, economic, and environmental dimensions of various sectors and the livelihoods that depend on it. Therefore, not only do these sectors require the implementation of decisive mitigation strategies to reduce GHG emissions, but also to expand established innovative adaptive measures.

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