Framework Convention on Climate Change

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Technology Executive Committee

07 March 2023

Twenty-sixth meeting

21–23 March and 24 March 2023 (TEC-CTCN Joint session)

Draft compilation of good practices and lessons learned on the setup and implementation of National Systems of Innovation

Cover note

I. Background

1. As per activity A.1.1 of workstream 1 of the Technology Executive Committee's (TEC) rolling workplan for 2023–2027,[1] the TEC is to continue work on National Systems of Innovation (NSI), including finalising the work begun under its previous workplan on the setup and implementation of NSIs.

2. Outputs for this activity in 2023 are:

(a) A compilation of good practices and lessons learned on the setup and implementation of NSIs, and

(b) A summary for policymakers and targeted stakeholders.

3. At TEC 24, the TEC provided guidance on the development of the compilation, emphasising the importance of building on previous work of the TEC on NSI and incubators and accelerators. The TEC also stressed the importance of elaborating on national and international linkages between the various actors involved in NSIs, including the role of the private sector and education institutions in supporting national innovation efforts, as well as how NSIs contribute to the implementation of NDCs.

4. At TEC 25, the TEC considered a first draft of the compilation and provided guidance on further work to be presented in an updated draft at TEC 26, including developing a summary for policymakers; increasing the number of case studies from four to six, with guidance provided for selecting the additional cases; enriching the comparative analysis between case studies; improving the user-friendliness of the tables and figures; and elaborating on the mobilisation of financial resources.

5. The TEC task force on innovation worked inter-sessionally, with the support of the secretariat and a consultant, to prepare an updated draft of the compilation. Key findings are summarised and outlined in a summary for policymakers, allowing readers to refer to the compilation for more detailed analysis.

II. Scope of the note

6. The annex to this note contains the updated draft compilation on good practices and lessons learned from the setup and implementation of NSIs analysing six case studies. Included in the compilation is the summary for policymakers, which will be extracted as a separate document after TEC 26.

[1] Available at https://unfccc.int/ttclear/tec/documents.html.

III. Expected action by the Technology Executive Committee

7. The TEC will be invited to consider the draft compilation and the summary for policymakers and provide guidance to the innovation task force with a view to finalising them after TEC 26 and launching them at SB 58.

Annex

Draft compilation of good practices and lessons learned on the setup and implementation of National Systems of Innovation

Compilation of

Good practices and lessons learned on setup and implementation of National Systems of Innovation (NSI)

(2nd Draft 7 March 2023)

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Foreword

The Technology Executive Committee (TEC) has long since been analysing and highlighting the central role of innovation and National Systems of Innovation (NSI) in supporting international and national efforts to enhance action on climate change and address developmental challenges. The TEC's earlier work on NSI points to strong dependencies between a country's capabilities to implement and benefit from technological change and the strength of its NSI.

We know that innovations related to clean technologies and their effective national and/or international diffusion play a critical role in the pace and cost of climate action. In its first chapter dedicated to innovation and technology development and transfer, published in 2022, the IPCC highlighted the importance of supporting developing countries in strengthening their technological innovation systems and innovation capabilities in order to accelerate international collaboration on innovation (IPCC, AR6, WGIII, chapter 16).

To this end, the TEC is pleased to present this compilation on good practices and lessons learned on the setup and implementation of NSIs. The compilation brings together six case studies that have successfully addressed the challenges of climate technology innovation in one way or another, leading to a well-functioning system, or parts thereof. In addition, the compilation provides concrete examples of factors that have driven or impeded innovation processes and the measures and approaches that have improved their effectiveness. They cover mitigation- and adaptation-related activities, different sectors, top-down and bottom-up approaches to stimulate innovation, different functions of innovation systems, and different country groupings.

Even though implemented in specific countries or sectoral contexts, the good practices shared can form a basis for cross-learning between sectors and regions. In addition, the recommendations provided can help policymakers chart a roadmap for strengthening their own national innovation systems – from the preparatory phase of developing an NSI to the design and implementation phase and the monitoring, evaluation, and revision of the NSI.

As the TEC begins implementing its new work plan, as well as the joint work programme of the UNFCCC Technology Mechanism for 2023-2027, the TEC remains committed to supporting local innovation through an NSI approach, recognizing the transformative potential of NSI as an important enabler of technology transfer and development.

The Technology Executive Committee extends its appreciation for the expertise and inputs provided by representatives of observer organisations in the development of this TEC Publication.

Ambrosio Yobanolo del Real
Chair of the Technology Executive Committee

Stig Svenningsen
Vice-Chair of the Technology Executive Committee

Highlights

Article 10, paragraph 5 of the Paris Agreement states that accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development. Countries' capabilities to drive and enable climate technology innovation are crucial in this regard. These capabilities are determined in part by the effectiveness of countries' national system of innovation (NSI). The recognition of good practices, even though implemented in specific country/sectoral contexts, can provide useful insights to support other countries in developing or strengthening such systems.

The primary aim of this compilation is to share lessons learned and good practices on the setting up and implementation of NSIs for the use of developing country policymakers looking to strengthen their NSI in the context of climate action. It aims to deepen the understanding of NSIs (or parts thereof) and identify measures and approaches which have improved the effectiveness of the national systems in specific cases and translate them into good practices that can be replicated in other countries and sectors.

To this aim, a number of case studies has been selected, taking into account the maturity and availability of information of the initiative, a balance between mitigation and adaptation technologies, sectors and geographic regions and income levels of the countries involved. The case studies include:

- The Indian Bureau of Energy Efficiency;
- The Kenya Climate Innovation Center;
- Haiti's Disaster Risk Reduction strategy;
- Brazil's bio-ethanol transport fuel activities;
- Jakarta's urban flood management activities;
- Denmark's wind energy sector.

Within the scope of this compilation it is not possible to evaluate entire national innovation systems, given their size and complexity. The assessment, therefore, looks at selected parts of NSIs, focussing on functions and structural components of innovation systems.

Main lessons learned and success factors that may be relevant to other countries are summarised in Figure H-1.

Figure H-1 Main lessons learned and success factors in designing and implementing NSIs

Drawing from the analysis of the case studies, the overall recommendation is that implementation of the NSI is best guided through a systematic approach that draws upon NSI functions and structure-function frameworks as a way to suitably organize efforts. Specifically, the objective would be to help ensure that the NSI is organized and resourced suitably so as to perform the functions required for successful innovation. But since many of the details are sector-specific, it is recommended that the process begins with an identification of sectoral priorities aligned with national policy goals and socio-economic objectives. This can subsequently guide and facilitate, as

needed, the process of strengthening NSI functions, marshalling resources, and addressing weaknesses and gaps in structural elements in NSIs.

Good practices for potential replication that have been identified in the various case studies lead to the following specific recommendations in the preparatory phase, the design and implementation phase, and for monitoring, evaluation, learning and revision:

Preparation recommendations

- Develop climate-action plan in alignment with long-term policy framework and socio-economic priorities;
- Map the NSI before designing and implementing strategies, taking into account potential unintended consequences where possible;
- Look for win-win measures;
- Engage both public and private sectors;
- Consider both bottom-up and top-down innovation routes.

Design and implementation recommendations

- Establish a clear role for a coordinating agency;
- Explore innovative, customized, and flexible funding frameworks;
- Put together a suitable mix of actors and policies;
- Allow flexibility in how policy goals are met;
- Pay attention to market creation for climate technologies;
- Focus beyond hardware innovation;
- Strengthen local capabilities, while ensuring coordination;
- Create complementary knowledge and servicing infrastructure;
- Maximize productive engagement with international actors and opportunities.

Monitoring, evaluation, learning and revision recommendations

- Ensure there is adequate and systematic monitoring, evaluation and revision;
- Evolve and improve through learning by doing and learning through analysis, including addressing unintended consequences;
- Adapt to evolving context and needs.

Most of these recommendations will be operationalized through the appropriate government entities that are tasked with planning, implementing, or monitoring and evaluating. But many are also relevant for **other audiences**. Multi- and bilateral organizations can use them in the design of their support activities for national governments and other stakeholders. Civil society organizations, citizens and communities can use them to strengthen their public engagement activities, particularly during the preparatory stages to ensure that the prioiritization is robust. They often also have knowledge to offer. The private sector is a critical stakeholder, although their role varies by issue at hand, for instance between adaptation and mitigation. Their engagement is important in the preparatory, design and implementation phases. Therefore many of the recommendations directly pertain to them, such as those relating to entrepreneurial opportunities, how to address barriers for development and deployment of their technologies, routes for successful ways to engage with local partners and stakeholders, and the importance of using appropriate impact assessment, forecasting and risk management tools. And lastly, academic/research organizations can use the lessons to help direct their research and educational activities to increase their relevance and effectiveness. They can potentially also play a role in the evaluation phase mentioned above.

Summary for policy makers

Effectiveness of NSIs is important for upscaling development and deployment of climate action

Article 10, paragraph 5 of the Paris Agreement states that accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change (both adaptation and mitigation) and promoting economic growth and sustainable development. Countries' capabilities to drive and enable climate technology innovation are crucial in this regard. These capabilities are determined in part by the effectiveness of its national system of innovation (NSI).

The primary aim of this compilation is to share lessons learned and good practices on the setting up and implementation of NSIs for the use of developing country policymakers looking to strengthen their NSI in the context of climate action. The analysis aims to deepen the understanding of (parts of the) NSIs[2] and identify measures and approaches that have improved the effectiveness of the national systems in specific cases and translate them into good practices that can be replicated in other countries or sectors. The recognition of good practices, even though implemented in specific country or sectoral contexts, can lead to cross-learning (exchange of knowledge and experience).

Effectiveness of an NSI depends on its ability to fulfil key 'functions'

An innovation system's overall **aim** is to 'produce, diffuse, and use' innovations. To achieve this goal, there are some specific activities that should be undertaken to facilitate the innovation process, for example the diffusion of knowledge. These activities are referred to as the **'functions'** an innovation system can perform. Functions explain 'what happens' in an innovation system, that is, the activities of the actors and/or organizations pursuing innovation, the role played by institutions in promoting or impeding innovations, and the impacts of the interactions between the various elements of the system. Based on empirical evidence, innovation studies identify seven main functions:

- F1 Knowledge development & diffusion;
- F2 Entrepreneurial experimentation;
- F3 Market formation;
- F4 Influence on the direction of search;
- F5 Resource mobilization;
- F6 Legitimation;
- F7 Development of positive externalities.

Evaluating to which extent an innovation system is able to perform these functions is necessary to identify and assess the innovation system's achievements, failures, and gaps or barriers. Such a 'functional analysis' enables the development of a comprehensive view of an NSI's operations, either retrospectively to identify lessons learned and strengthen existing NSIs, or prospectively, as a guide to systematic action when putting in place policies to achieve specific climate objectives.

The extent to which the various functions can be performed effectively depends on whether '**structural components'** are present and of sufficient quality. These components include actors, institutions, interactions (or networks) and technologies (including infrastructure). A system's underachievement can be directly related to absences or weaknesses in these structural components.

Improving an NSI's effectiveness requires looking at its functional performance (*what* is going well and *what* is not?), as well as at the reasons behind the observed performance (*why* it is going well or why not?). This is done by coupling the evaluation of the overall functional performance of the system with an analysis of its structural components. This type of 'structure-function coupled analysis' facilitates the identification of situations where e.g., insufficient actor capabilities or inadequate policy environments are the main cause behind an ill-functioning system. It also allows the identification of opposite situations, i.e. where specific actors or policies play a key role in strengthening the functions of the system. In this report, such a structure-function analysis has been applied to six case studies to identify lessons learned and good practices.

[2] Within the current scope it is not possible to evaluate entire national innovation systems, given their size and complexity. Therefore, the assessment looks at selected parts of NSIs.

Lesson learned and good practices identified through case studies

Six case studies have been selected across a range of countries, covering both mitigation and adaptation initiatives and including an appropriate representation across regions and country income groups as well as sectors. The case studies also cover different innovation system perspectives (national/sector/technology-focused, top-down/bottom-up). Cases were also selected keeping in mind the need to be sufficiently mature to facilitate meaningful evaluation, have a potential for providing good practices and/or useful lessons learned and sufficient availability of information.

Table SPM-1 below summarises the characteristics and lessons of the case studies. These have been synthesized into a number of generic lessons and recommended good practices[3]:

1. Take a systemic perspective towards the establishment/strengthening of the NSI, integrated with host country development objectives (all cases)…
   The build-up of an NSI need to be aligned with the country's development priorities for legitimation and long-term support. Once climate policy goals have been defined in the context of national socio-economic objectives, the interactions between mitigation, adaptation and sustainable development become clear. Such a systemic perspective makes it possible to define with some specificity the strategic prioritization of sectors and overall innovation needs. At the same time, such a perspective also requires some long-term visioning and planning.

2. ... yet a tailored approach to bridging sector- and innovation phase-specific gaps (all cases)
   Notwithstanding the required systemic perspective (#1 above), a tailored approach to the development of an NSI is needed, given that innovation needs vary from sector to sector. This, in turn, requires a comprehensive understanding of gaps and barriers related to specific sectors and specific phases of the innovation cycle. Such an approach is underpinned by a systematic focus on innovation system functions that need to be addressed as well as the structural elements (actors, institutions, interactions, and infrastructure) that can help in specific sectors.

3. Leadership with a collaborative attitude and an understanding of local context: One common and significant feature of the case studies (particularly BEE, KCIC and Jakarta cases) is the importance that initiatives are led by people and/or organizations with a broader and nuanced understanding of the local innovation system. This helps in engaging the right kind of actors, marshalling the right kind of resources, identifying and addressing the gaps in the innovation process, and tapping into the complementary structures and processes of the overall innovation system to advance the climate initiatives. If the capabilities and decision-making in a project are dominated by actors that are not locally grounded, such processes may stall (see also #4). Specific organizations that are able to take the lead (e.g., BEE. KCIC) can play a key role as 'integrators' or 'coordinators' of the various structural and functional aspects of the innovation system. The overarching and interactive functioning of the leading organizations can facilitates not only coordination among actors but also addressing gaps such as financial resources, enabling policy frameworks, or human and institutional capacity.

4. Participation of/interactions among local actors facilitates innovation and alignment (all cases)
   Participation of, and interactions, among domestic actors (at the national and sub-national level) is key since they have the best understanding of local context and institutions, they often have the largest stake in the outcome, and therefore are best placed to help fill gaps in, and advance functions of, the innovation system. Therefore, promoting such interactions is critical, whether among knowledge institutions such as universities, between knowledge institutions, firms and government agencies, between firms and communities, among government agencies, etc. In the case studies on first-mover countries for specific technologies (Brazil, Denmark), networks between actor groups were key for moving the technology along the innovation cycle and the formation of markets. In the case of BEE, the Bureau drew upon existing networks, expanding them to facilitate the flow of knowledge (such as international best practices) as well implementation of programmes.

5. Engage with international institutions and collaborations to help build local institutions, networks (BEE, KCIC, Haiti DRR, Jakarta)

[3] see Table 18 in Section 4.2 for the translation of case-specific lessons to these generic lessons and recommentations.

International institutions can play an important role in strengthening NSIs by bringing in global best practices, assisting with development, adaptation and diffusion of new technologies, helping mobilize financial and technical resources, and building capabilities of local actors and institutions. But engagement with such institutions is likely to be most effective when based on an understanding of local innovation needs and gaps. For KCIC, international actors combined forces with local actors to create the center and generate capabilities and knowledge, which was subsequently shared again internationally, amongst others in the network of CICs. Haiti benefitted strongly from the activities of the Sahana volunteer network, applying internationally developed tools and knowledge locally, which in turn improved multilateral agencies responses.

6. Ensure that innovation and organizations are evolutionary and able to adapt to new circumstances, through continuous monitoring and review (all cases)
   The innovation context, capabilities, and resources change over time and therefore so do innovation needs. At the same time, analysis of the functioning of the NSI may also yield insights as to how to strengthen the NSI and make it more effective. Adapting to the changed circumstances and emerging knowledge so as to remain relevant and effective may mean engaging with new actors or addressing new functions of the NSI, e.g. with different types of interventions. It may also mean that organizations themselves evolve over time. Therefore, continuous monitoring and evaluation of innovation needs and outcomes, and the ability to adapt in in response, takes on great importance. The insights from such monitoring and review can be used to improve the setup and implementation of the NSI, thereby creating a dynamic situation where the NSI is able to evolve in response to the new knowledge and understanding. It can provide a better understanding of long-term policy goals to innovation actors, allowing for course correction, when and where needed.

7. Portfolio of solutions (all cases)
   The scale and complexity of climate change adaptation and mitigation challenges in the context of sustainable development as well as the diversity of a national system of innovation means that the intervention also cannot be singular. It requires a portfolio of measures to strengthen the relevant functions across the innovation cycle and to build capacity with a variety of actors. Different sectors, innovation cycle phases and actors will have different needs, benefitting from a range of tailor-made approaches, including in many cases a combination of both top-down and bottom-up approaches are used interactively and iteratively.

8. Deal with structural problems (Jakarta, Haïti DRR, Brazil)
   In some cases, the underlying problems of poverty, lack of influence and voice and environmental or social challenges are not acknowledged when designing the intervention, or only becoming clear during the intervention. Focusing on broader development goals, NSI functions and including all stakeholders usually addresses this, but structural problems may rebound. Even when solving them is beyond the capacity of a climate action project, attention for these structural problems needs to be part of an integrated approach.

Table SPM-1 Summary of case studies and key lessons learned

Case	Focus	Lessons learned

India BEE	• Mitigation
	  ○ energy demand
	• Top-down
	• Main IS functions:
	  ○ F1 Knowledge development & diffusion
	  ○ F2 Entrepreneurial experimentation
	  ○ F3 Market formation
	• International support received:
	  ○ Some of the initiatives tapped on international technical expertise, e.g., S&L Programme drew on the expertise of CLASP.
	  ○ Engagements with CLASP also facilitated funding opportunities with USEPA, USAID, etc.
	  ○ The standards used in the UJALA programme were devised by an international expert group.
		• A tailored approach is required as innovation needs vary from sector to sector
		• Bridging sector-specific gaps is key
		• Innovation activities need to be strategic, iterative and evolutionary
		• Coordination and integration of NSI elements is crucial
		• Strategic prioritization of focus sectors improves efficiency, credibility and legitimacy

Kenya CIC	• Mitigation & adaptation
	  ○ Energy, agriculture, water, waste management
	• Top-down
	• Main IS functions:
	  ○ F F1 Knowledge development & diffusion
	  ○ F2 Entrepreneurial experimentation
	  ○ F3 Market formation
	  ○ F5 Resource mobilization
	• International support received:
	  ○ International support and collaborations (consortiums) to build local technical and innovation capacity, project management capacity, etc. For instance, CTCN is working with KCIC to help Kenyan SMEs adopt efficient technologies
	  ○ International support to generate funds for R&D, innovation, projects, etc.
	  ○ International support to mobilise policy and market action to create an enabling setting for climate action
		• Organizations need to evolve and diversify with time to achieve their goals
		• Collaborative, multi-actor partnerships are crucial for effective climate action
		• Funding model design needs to be sector/innovation cycle phase-specific
		• Full integration with host country development objectives is needed for effective outcomes
		• Local actors' engagement in the design is crucial for effectiveness
		• Effective interaction among local actors is vital for peer learning
		• International institutions and collaborations can help build local institutions and networks

Haiti DRR	• Adaptation	• Taking a systemic perspective is important

	○ Disaster Risk Reduction in all sectors • Top-down & bottom-up • Main IS functions: ○ F1 Knowledge development & diffusion ○ F4 Guidance of the search ○ F5 Resource mobilization ○ F6 Legitimation • International support received: ○ Technical cooperation and capacity building for elaborating the national plan from e.g, UNEP ○ Funding from bilateral donors for educational and training programmes ○ Financial support for disaster recovery from multi/bilateral institutions, including CCRIF ○ Contribution from volunteers, e.g, Sahana	• Local knowledge and needs need to be taken on board • Strong networks are crucial in coordination • Combined top-down and bottom-up efforts can create synergies • Multi-stakeholder partnerships, including international collaboration is important • Systemic change requires time • Long-term planning and continuous review are important
Brazil bio-ethanol	• Mitigation ○ Transport (Energy/Agriculture) • Top-down & bottom-up • Main IS functions: ○ F1 Knowledge development and diffusion ○ F2 Entrepreneurial experimentation ○ F3 Market formation ○ F5 Resource mobilization ○ F6 Legitimation ○ F7 Development of positive externalities • International support received: not applicable, although international developments resulted in economic opportunities by creating international markets	• For successful innovation, both technology-push and technology-pull policies are needed • Innovation policies and coordination are needed across the value-chain • A mix of bottom-up and top-down measures facilitate innovation • Coordination between knowledge producers and users accelerated diffusion • Aligning technological development to societal goals facilitates formation of coalitions that provide political support and legitimacy • Innovation takes time, is uncertain, and highly dynamic • International aspects can influence the development of local innovation systems, intentionally or not. • Local support for technology innovation and early market formation increased the country's ability to compete in international markets • Capabilities are needed across all stakeholders Multi-stakeholder partnerships, including international collaboration is important
Jakarta urban flood manage-ment	• Adaptation ○ Urban flood management • Top-down and bottom-up • Main IS functions: ○ F1 Knowledge development and diffusion ○ F5 Resource mobilization	• Integrated and collaborative governance is crucial • Complex problems require a portfolio of strategies • Focus on chronic problems and root causes is essential • Adaptive governance and continuous learning are crucial • Building capacities of local governments and agencies is important • Future risk assessment and long-term planning is indispensable

	• International support received:
	  ○ Support/collaborations for scientific studies on vulnerability & risk assessments, potential solutions
	  ○ Capacity building, awareness generation, knowledge diffusion and projects
	  ○ Building project consortia/public private partnerships to create investment opportunities for various stakeholders
	  ○ Funds for R&D, innovation, projects, etc.,
		• Convergence of DRR, climate change adaptation and development processes is crucial
		• Risk governance needs to go beyond technical strategies, requiring a people-centered approach
		• Community preparedness is key
		• Context specificity of knowledge has implications for knowledge- and technology-transfer outcomes
		• Engaging local communities in developing EWSs increases capacity to respond during emergencies

Denmark wind energy	• Mitigation
	  ○ Energy supply
	• Top-down & bottom-up
	• Main IS functions:
	  ○ F1 Knowledge development and diffusion
	  ○ F2 Entrepreneurial experimentation
	  ○ F3 Market formation
	  ○ F4 Guidance of the search
	  ○ F5 Resource mobilization
	  ○ F6 Legitimation
	  ○ F7 Development of positive externalities
	• International support received: not applicable, although international markets resulted in economic opportunities by creating international markets
		• For successful innovation, both technology-push and demand-pull policies are needed.
		• A dynamic interaction and synergy between bottom-up and top-down measures facilitates innovation
		• Coordination between knowledge producers and knowledge users accelerates technology development and diffusion
		• Multi-stakeholder partnerships, including international collaboration is important
		• Aligning technological development to societal goals can facilitate formation of coalitions that provide political support and legitimacy
		• Participatory approaches increase ownership and public acceptance
		• International aspects can influence the development of local innovation systems, intentionally or not
		• Local support for technology innovation as well as early market formation increased the country’s ability to compete in international markets

Overall conclusions and recommendations

The analysis in this compilation underlines the value of a systematic approach to strengthening relevant parts of national systems of innovation that can support and advance climate action through scaled up development and diffusion of climate technology for both adaptation and mitigation. The NSI functions and the structure-function framework used can serve to guide the systematic approach to implement the NSIs to advance climate action.

Good practices for potential replication that have been identified in the various case studies lead to the following specific recommendations. Here, we make a distinction between the preparation for actions to align the NSI with climate action, recommendations to design and implement efforts to strengthen the NSI's contribution to climate action, and monitoring/evaluation/revision of the NSI's contribution to climate action. This is done, however, with the understanding that the boundaries between these phases is not strict.

Preparation recommendations

⇒ *Develop climate-action plan in alignment with long-term policy framework and socio-economic priorities:* It is essential to ensure that climate actions are in synergy with the overall policy framework of the country and that it facilitates the country's overall development and climate objectives. This has two benefits:

1. It allows for clear articulation of priority areas/sectors, which will help efforts to suitably strengthen the NSI; and
2. Synergies with local objectives (such as livelihoods, gender parity) will also help enhance buy-in and participation by stakeholders.

⇒ *Map the NSI before designing and implementing strategies:* Such mapping helps create the needed understanding of the existing structural elements and functions of the innovation system, barriers and missing links in the innovation ecosystem, crucial actor groups, state of resources and capabilities, potential synergies and trade-offs between other initiatives and policy structures, and the role of international collaborations. This knowledge can inform and guide subsequent efforts to strengthen the NSI and make them more effective.

⇒ *Look for win-win measures:* It is important to design win-win strategies (through, for example, an appropriate choice of focus area, innovative governance and market models) to ensure participation and acceptance by all relevant stakeholders and minimization of risk factors.

⇒ *Engage both public and private sectors: E*nsure the participation of diverse stakeholders to address the complexities and uncertainties associated with innovation processes. This will also help in tapping into the capabilities and skill sets of a range of actors. Here it is important to note that the above are crucial in the preparatory phase, but that it is important that they continue to be applied during the implementation phase.

Design and implementation recommendations

⇒ *Establish a clear role for a coordinating agency*: In situations where diverse stakeholders need to come together to make an intervention/innovation effective, the role of coordinating agencies or 'system operators/integrators' becomes important. Coordinating agencies with a holistic understanding of the strengths and shortcomings of the NSI can organize and coordinate the actions of different stakeholders, tap into resources and strengths of various actors, and address other system gaps to maximize impact.

⇒ *Explore innovative, customized, and flexible funding frameworks*: Explore funding models to suit the stage, scope, and risk perception of the innovators/firms. Complement funding schemes with enabling policy and financial regimes for effective and sustained outcomes.

⇒ *Put together a suitable mix of actors and policies*: to accommodate the wide range of actors and innovation phases, a mix of policies is needed, providing both technology push and technology pull type incentives, and engaging both bottom-up and top-down actors.

⇒ *Allow flexibility in how policy goals are met*: This is particularly relevant in a developing country context. Where possible, the policy goals and aspirations should be defined, with the stakeholders given the flexibility to adopt the technology/means that suit them best to achieve those goals (e.g. be technology-neutral). This will generate credibility for policy implementation, manage risk perceptions of stakeholders, and facilitate faster attainment of policy goals.

⇒ *Pay attention to market creation for climate technologies*: For a mature and effective ecosystem for green innovation, policies, market structures, and actor capabilities should be directed towards creating sustained demand and supply dynamics for clean technologies.

⇒ *Focus beyond hardware innovation:* Technological hardware can have an important contribution to mitigation and adaptation goals. However, this should be combined with building the capacity of local actors, creating the right communication channels for sharing knowledge and information, and establishing the right regulatory framework for an effective strategy to scale up implementation of climate technology.

⇒ *Strengthen local capabilities, while ensuring coordination:* Strengthening local capabilities is crucial for effective action. However, there is also a need for harmonization of curricula, protocols and information management mechanisms. Finding the right balance between bottom-up and top-down processes can be challenging, but can contribute to more effective strategies.

⇒ *Create complementary knowledge and servicing infrastructure*: In order to promote and implement technological innovations effectively and consistently (in the long term), the creation and retention of complementary knowledge, skill sets, and a trained human resource base must be facilitated. This will also aid in monitoring, evaluating, and upgrading technological innovations.

⇒ *Maximize productive engagement with international actors and opportunities*: International partnerships and exchanges can be very useful in learning from others' experiences and best practices. They also can help develop local technological, financial, political, and human resources. Therefore international engagement can help strengthen the NSI in many different ways but that also requires local actors actively shaping and driving this engagement. Furthermore, the international arena may well offer market opportunities that could be very productive.

Monitoring, evaluation, learning and revision recommendations

⇒ *Ensure there is adequate and systematic monitoring, evaluation and revision:* Since systemic change requires time, short-term planning (with too short time frames covering only a few years) will only be effective to a limited degree in achieving objectives. It is therefore important to plan according to longer time frames, while continuously taking account progress made, and reviews where necessary.

⇒ *Evolve and improve through learning by doing and learning through analysis*: Learning comes both from evaluation and review-based analysis as well as experimental learning by doing. These are complementary forms of learning and both should be utilized as the basis for constant enhancement of the NSI through the strengthening of functions and structural elements.

⇒ *Adapt to evolving context and needs:* Climate actions will be ongoing activities, and the social, economic, and political context and needs likely will evolve over time. Therefore, NSI actors and institutions will also need to adapt and evolve over time in line with these changes. This responsiveness and dynamism has to be part of the institutional design from the early stages so the NSI continues to be relevant and useful in helping deliver successful climate action over time.

Most of these recommendations will be operationalized through the appropriate government entities that are tasked with planning, implementing, or monitoring and evaluating. But many are also relevant for **other audiences**. Multi- and bilateral organizations can use them in the design of their support activities for national governments and other stakeholders. Civil society organizations, citizens and communities can use them to strengthen their public engagement activities, particularly during the preparatory stages to ensure that the prioiritization is robust. They often also have knowledge to offer. The private sector is a critical stakeholder, although their role varies by issue at hand, for instance between adaptation and mitigation. Their engagement is important in the preparatory, design and implementation phases. Therefore many of the recommendations directly pertain to them, such as those relating to entrepreneurial opportunities, how to address barriers for development and deployment of their technologies, routes for successful ways to engage with local partners and stakeholders, and the importance of using appropriate impact assessment, forecasting and risk management tools. And lastly, academic/research organizations can use the lessons to help direct their research and educational activities to increase their relevance and effectiveness. They can potentially also play a role in the evaluation phase mentioned above.

1 Introduction

Article 10, paragraph 5 of the Paris Agreement states that accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development. Countries' capabilities to drive and enable climate technology innovation are crucial in this regard. These capabilities are determined in part by the effectiveness of its national system of innovation (NSI).

The primary aim of this compilation is to share lessons learned and good practices on the setting up and implementation of NSIs for the use of developing country policymakers looking to strengthen their NSI in the context of climate action. The analysis aims to deepen the understanding of (parts of the) NSIs[4] and identify measures and approaches that have improved the effectiveness of the national systems in specific cases and translate them into good practices that can be replicated in other countries or sectors. The recognition of good practices, even though implemented in specific country or sectoral contexts, can lead to cross-learning (exchange of knowledge and experience).

To this aim, six case studies have been selected across a range of countries, covering both mitigation and adaptation initiatives and including an appropriate representation across regions and country income groups, as well as sectors. The case studies also cover different innovation system perspectives (national/sector/technology-focused). Cases were also selected keeping in mind the need to be sufficiently mature to facilitate meaningful evaluation, have a potential for providing good practices and/or useful lessons learned and sufficient availability of information.

The next section introduces the concepts and the approach used in this report. Table 1 provides an overview of the case studies selected. The detailed discussion of the case studies can be found in section 3 of this compilation. Section 4 summarizes the lessons learned and identified good practices across case studies, on the basis of which Section 5 presents some key recommendations for enhancing NSIs.

[4] Within the current scope it is not possible to evaluate entire national innovation systems, given their size and complexity. Therefore, the assessment looks at selected parts of NSIs.

Table 1 Overview of the selected case studies

Case study	Country - region	Mitigation/ adaptation	Sector	Type of country/ income level	Top-down/ bottom-up	Main IS functions
BEE Bureau of Energy efficiency	India – Asia	Mitigation	Energy efficiency – economy wide	Lower Middle Income	Top-down	F1 Knowledge development & diffusion F2 Entrepreneurial experimentation F3 Market formation
KCIC Kenya Climate Innovation Center	Kenya – Africa	Mitigation + adaptation	Energy (renewable energy + energy efficiency), agriculture, water, waste, forestry	Lower Middle Income	Top-down	F1 Knowledge development & diffusion F2 Entrepreneurial experimentation F3 Market formation F5 Resource mobilization
Disaster Risk Reduction	Haiti – Caribbean	Adaptation	All sectors	Low-Income	Top-down & bottom-up	F1 Knowledge development & diffusion F4 Guidance of search F5 Resource mobilization F6 Legitimation
Bio-ethanol activities	Brazil – Latin America	Mitigation	Transport (energy/ agriculture)	Upper Middle Income	Top-down & Bottom-up	F1 Knowledge development and diffusion F2 Entrepre-neurial experi-mentation F3 Market formation F5 Resource mobilization F7 Development of positive externalities
Urban flood management	Jakarta, Indo-nesia - Asia	Adaptation	Urban flood management	Upper Middle Income	Top-down & bottom-up	F1 Knowledge development and diffusion F5 Resource mobilization
Wind energy sector	Denmark – Europe	Mitigation	Energy supply	High Income	Top-down & bottom-up	F1 Knowledge development and diffusion F2 Entrepreneurial experimentation F3 Market formation F4 Guidance of the search F5 Resource mobilization F6 Legitimation F7 Development of positive externalities

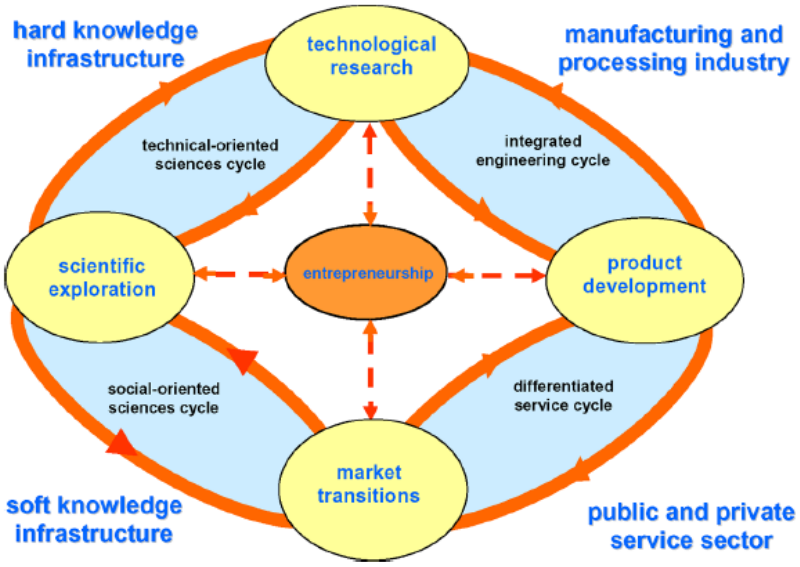
2 Concepts and approach

2.1 Definitions and concepts – Innovation and Innovation Systems

Innovation

'Innovation' has been defined in a myriad of ways, but the idea of 'newness' is central to most interpretations[5]. In short, innovations 'are new creations of economic significance' and could be either completely new (radical) or an amalgamation or improvization (incremental) of the existing elements[6]. Innovation is both the process and the outcome of creating something new that adds value to the broader domains of economy and technology. Innovations can relate to processes or products. Process innovations include organizational and technological changes, while product innovations include changes in materials, goods or services. Innovation relates not only to new-to-the world products and knowledge. When a product is first used in a certain context, this can also be an innovation. Innovation is often conceptualised in phases and can be enhanced through policy instruments (see Figure 2). Innovation can be driven from the top down – through government policies or centralized actions of main actors -, or from the bottom up – by (groups of) individual innovators. Often it is a combination of both, in an iterative process.

Figure 1 Different disciplines, sectors and actors involved in innovation and their interactions [7]



The recent IPCC Sixth Assessment Report on Mitigation for the first time contained a chapter on innovation.[8] It emphasises that innovations occur in dynamic processes emerging from interactions between different actors and between R&D, economic application, and further improvization through learning-by-doing and learning-by-using. Actors engaged in the development and diffusion of technologies interact via networks, and the

[5] Johannessen, J. A., Olsen, B., & Lumpkin, G. T. (2001). Innovation as newness: what is new, how new, and new to whom?. *European Journal of innovation management*.

[6] Edquist, C. (1997). Systems of innovation approaches–their emergence and characteristics. Systems of innovation: Technologies, institutions and organizations, 1989, 1-35.

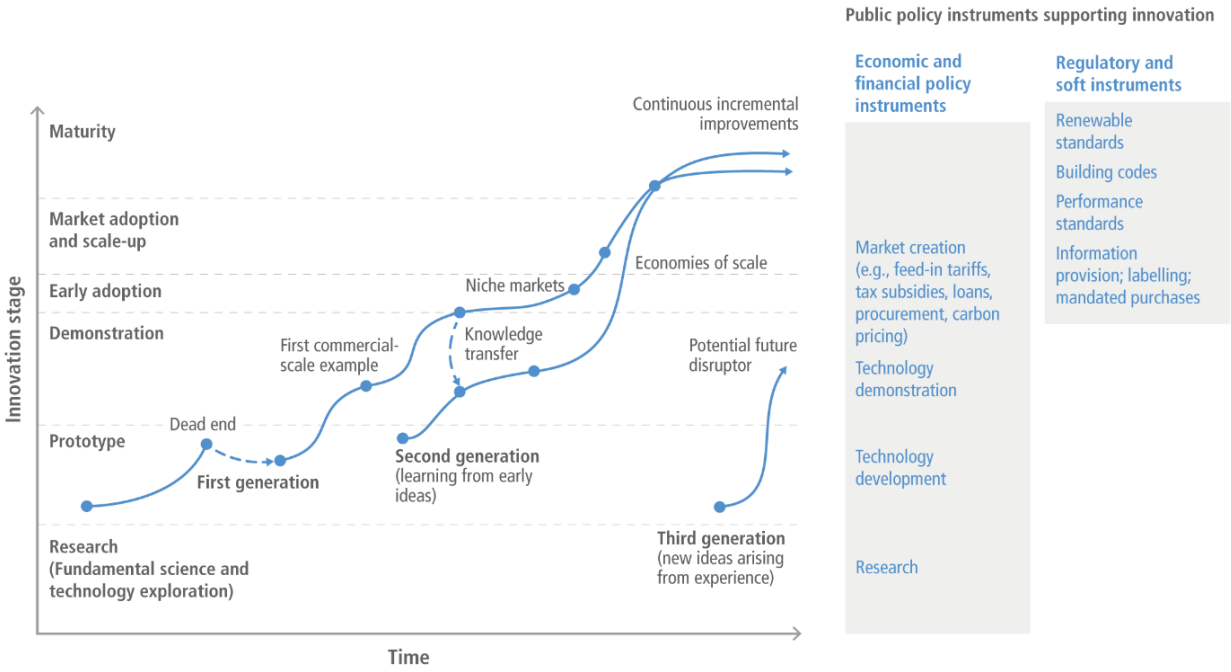
[7] Duin, Patrick & Ortt, Roland & Kok, Matthijs. (2007). The Cyclic Innovation Model: A New Challenge for a Regional Approach to Innovation Systems?. European Planning Studies. 15. 10.1080/09654310601078689. https://www.tandfonline.com/doi/abs/10.1080/09654310601078689?journalCode=ceps20

[8] Blanco, G., H. de Coninck, L. Agbemabiese, E. H. Mbaye Diagne, L. Diaz Anadon, Y. S. Lim, W.A. Pengue, A.D. Sagar, T. Sugiyama, K. Tanaka, E. Verdolini, J. Witajewski-Baltvilks, 2022: Innovation, technology development and transfer. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.018

interactions are regulated by institutions which include formal rules, such as laws, and informal restraints, such as cultural values and codes of conduct. Furthermore, the innovation process is systemic and inherently non-linear due to interactions between science, technology, policy, economics, learning, etc. There are several feedback loops in technological development, for instance, between knowledge generation, knowledge translation and application, and knowledge use. This implies that innovations do not come only from R&D, but also from production engineers and the shop floor, for example (see also Figure 1). This explains the high levels of path-dependence and inertia that impedes innovation, including introducing cleaner technologies, processes, and organizations.

The systemic nature of innovation assessed in the IPCC chapter on innovation is taken as a basis for this compilation. While there has been much effort and positive results in innovation for climate technology over the past years, the IPCC also notes that innovation also comes with trade-offs, such as negative externalities and rebound effects. Furthermore, it highlights that developed countries tend to benefit more from innovation than developing countries. The trade-offs and the inequalities that innovation, if not managed well, may exacerbate make it key to study the conditions for innovation.

Figure 2 Technology innovation process and two (illustrative) roles of different public policy instruments[9]



The TEC has been analyzing and highlighting the significance of innovation in achieving the purpose of the climate and Sustainable Development Goals. The latest TEC Brief on Innovative approaches to accelerating and scaling up implementation of mature climate technologies[10] notes that effective implementation of technologies for climate mitigation and adaptation calls for not only technical innovations but also innovations in the way actions are planned, actors collaborate, and funding is sourced. These innovations facilitate government action to 'push' and market forces to 'pull' these technologies for wider implementation. Earlier work by the TEC on energizing entrepreneurs to tackle climate change also explicitly acknowledges the importance of entrepreneurs in developing technologies, business models and services for low-emission and climate-resilient sustainable development.[11]

[9] Source: IPCC 2022: Figure TS.27

[10] TEC Brief 14, 2021 Brief, Innovative approaches to accelerating and scaling up implementation of mature climate technologies.
https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/brief14/c4e1c145de494f2ea43c37dfd742f9e5/06260bdc8782406ab442084dc64ccf94.pdf

[11] TEC, 20, TEC Brief #12 Energizing Entrepreneurs to Tackle Climate Change, UNFCCC Technology Executive Committee, Bonn, https://unfccc.int/ttclear/tec/brief12.html

Systems of Innovation

The idea of Systems of Innovation (SI) is an established conceptual framework for studying innovation processes while taking into account their systemic nature, and can generate insights for policy makers[12]. "The elements and relationships which interact in the production, diffusion, and use of new, and economically useful, knowledge" comprise a system of innovation[13]. An innovation system is made of 'components, relationships, and attributes'[14]:

- **Components** are the 'operating parts' (actors, organizations, and institutions);
- **Relationships** are the market and non-market inter-linkages between the components (feedback mechanisms; technology spill-overs, transfer, acquisition, etc.); and
- **Attributes** are the properties and capabilities of the components which characterize the system (systems' robustness, flexibility, ability to generate change and respond to changes).

TEC Brief #7 on strengthening NSIs defines an NSI as "a network of actors, institutional contexts and linkages that underlie national technological change, existing of:

- **Actors**: Organizations that participate in technology development and transfer, e.g. technology firms, universities and financiers;
- **Institutional context**: Norms, cultural practices and laws that shape actor efforts, e.g. government policies that affect how the private sector invests in a particular sector;
- **Linkages**: Interactions and relations between the actors and the institutional context, e.g. flows of information and knowledge, and collaboration between firms, universities and research institutes".[15]

The concept of SI has been defined and understood at different complementary analytical levels, such as the national systems of innovation (NSI), regional systems of innovation (RSI), sectoral systems of innovation (SSI), and technological innovation system (TIS). These systems are conceptualised as fulfilling "functions" for technology development and deployment, and also technology transfer. As such functions are often weaker in developing countries, the link between systems of innovation and the technology development and transfer discussions in the UNFCCC and its Paris Agreement are eminent.[16] Deliberations on regulatory frameworks and research priorities at the international level impact the systems of innovations operating at the national, regional, and sub-national levels.

The system boundaries between TIS, SSI, NSI, and the global innovation systems (GIS) are artificial and set up by researchers according to the case study in question[17]. In practice, systems are interconnected (Figure 3). This means that when looking at an initiative aiming to foster innovation for climate action at the national level (shown as a green square in the graph), this may cover different technologies and sectors (the different SSIs, shown in blue). Importantly, actors, institutions, technologies and interactions may come also from the international level (shown in yellow) and interact with those at the national level (crossing the boundaries between different NSIs).

[12] Blanco et al., 2022

[13] Lundvall, B. Å. (2016). National systems of innovation: towards a theory of innovation and interactive learning. *The Learning Economy and the Economics of Hope*, *85*.

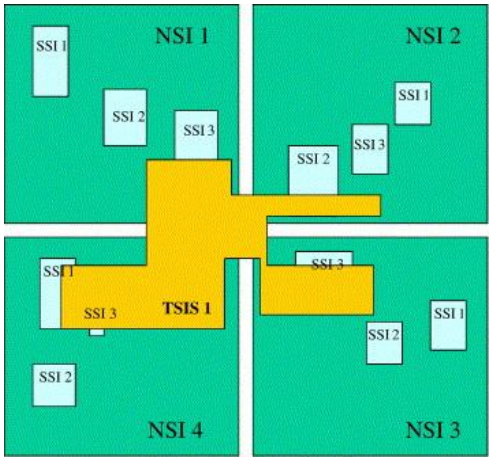
[14] Carlsson et al., 2002

[15] TEC, 2015, TEC Brief #7, Strengthening National Systems of Innovation to Enhance Action on Climate Change, UNFCCC Technology Executive Commission, Bonn, https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEC_documents/5be1bf880cc34d52a4315206d54a711b/60d1580f741a4bc783da5a00cf64a879.pdf

[16] Blanco et al., 2022

[17] Binz, C., & Truffer, B. (2017). Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. Research policy, 46(7), 1284-1298.

Figure 3 Boundary relations between National, Sectoral, and Technology Specific Innovation Systems[18] (for an explanation, see the main text above)



National Systems of Innovation and international linkages for climate action

As outlined in TEC Brief #7, the NSI plays a central role in determining the effectiveness of a country's climate action and its initiatives to address developmental challenges. A country's capabilities to implement and benefit from technological change is shaped by the strength of its NSI and its linkages with international innovation activities and systems. The pace and cost of climate action critically depend on innovations dealing with cleaner technologies [19] and effective international diffusion.

The interconnections and exchanges between the NSIs and the international context (the Global Innovation system (GIS)) are particularly relevant in the context of climate change. For instance, most successful cases in the energy transition have involved international collaboration[20], with clean energy technologies rarely being developed in a single country and then physically transferred to another. International actors and collaborations can play a far-reaching role in complementing, catalyzing, and accelerating national efforts on strengthening NSIs by drawing on wide-ranging global experiences and expertise.

The analysis in this compilation aims to cover innovation systems that are relevant for climate change mitigation and/or adaptation technologies, which can have a national, sectoral or technology focus. Linkages of the national component to international actors and processes will be taken into account.

2.2 Approach to understanding NSI performance for climate action

This compilation aims to deepen the overall understanding of NSIs or elements of NSIs (initiatives by actors situated within the NSI) and thereby identify strategies, actions, or factors that can effectively contribute to national climate and development goals, explicitly the development and transfer of climate technologies. Although implemented under specific local and global contexts, the successful strategies or structures can form a basis for cross-learnings between regions and sectors and can lead to improvements in systems elsewhere. From the policy perspective, an enhanced understanding of the national systems of innovation can help

[18]Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting and social change, 74(4), 413-432.

[19] See e.g. IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:10.1017/9781009157940.001

[20] See e.g., Gallagher, K. S. (2014). The globalization of clean energy technology: Lessons from China. MIT press. and Li, D., Alkemade, F., Frenken, K., & Heimeriks, G. (2022). Catching up in clean energy technologies: a patent analysis. The Journal of Technology Transfer, 1-23.

recognize the 'leverage points' for strengthening the country's innovative performance and its overall competitiveness.

In general, innovation outcomes depend on the overall functioning of the innovation system. There are different approaches for assessing such performance. This can range from the use of relatively simple **indicators** to an analysis of existing **barriers and enablers,** or based on the **functions** that a technology innovation system aims to perform. As discussed in TEC Brief #7, the indicator approach aims to measure a country's effort spent to stimulate innovation, a barrier approach focuses on what can hinder innovation from taking place, while a functional approach aims to assess the overall functioning of the innovation system, in terms of how well key processes are being carried out[21].

Performance indicators can include input indicators and/or output indicators. Examples of indicators include national R&D investments, the number of scientific publications or the number of patents generated. While these indicators are relatively simple to assess, they are also limited in the extent to which they can help understand and improve NSIs, as they focus on only part of what constitutes an effective innovation process.

A broader perspective looks at **barriers** for innovation, beyond the availability of R&D funding. Here, the performance of NSIs is defined in terms of whether (and to what extent) barriers or systemic failures have been identified and addressed and whether (and to what extent) the desired objectives of the system are accomplished. In simple terms, barriers are factors that impede the development, acquisition, and diffusion of technologies and innovations[22]. The UNFCCC Technology Needs Assessment (TNA) initiative strives to help countries identify their climate technology needs and priorities, analyze bottlenecks to effective diffusion of priority technologies, promote national development and build countries' innovation systems.

The findings of developing countries' TNAs show that barriers are not only technical in nature, but that that they hinder the overall evolution of the innovation system. Barriers to climate technology innovation, development and transfer can occur in the entire innovation system. They are context specific, but a lack of financial resources, the local regulatory environment or a lack of human capital are examples of commonly identified barriers. Barriers go beyond what can be captured by traditional indicators such as funding for R&D and the number of patents generated. In fact, they include also network failures, policy and regulatory barriers, awareness, and even cultural aspects. [23] These barriers link to four types of **resources** for innovation that need to be mobilized and coordinated for successful innovation systems: **knowledge, market formation, financial and human resources, and legitimacy**[24]. These resources allow the innovation systems to perform a range of **functions** needed to achieve successful innovations.

An innovation system's overall **aim** is to 'produce, diffuse, and use' innovations[25]. However, in order to recognize and influence the factors which drive or impede those processes, it is crucial to identify and understand in more detail the specific activities the systems (should) undertake to achieve the intended goals. This is – for a TIS – referred to as the different 'functions' of the innovation system. Functions explain 'what happens' in an innovation system, the activities of the actors and/or organizations pursuing innovation, the role played by institutions in promoting or impeding innovations, and the impacts of the interactions between the various structural elements.
Table 2 lists the functions of a TIS distinguished in literature.

[21] Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research policy, 37(3), 407-429.
[22]Nygaard, I., & Hansen, U. E. (2015). Overcoming barriers to the transfer and diffusion of climate technologies. (2nd ed.) UNEP DTU Partnership. TNA Guidebook Series http://www.tech-action.org/Publications/TNAGuidebooks
[23]UNFCCC, 2020: Fourth synthesis of technology needs for non-Annex I parties.
https://unfccc.int/documents/218506
[24] Binz, C. Truffer, B., and L. Coenen (2016). Path Creation as a Process of Resource Alignment and Anchoring: Industry Formation for On-Site Water Recycling in Beijing. *Econ. Geogr.*, **92**, 172–200,
https://doi.org/10.1080/00130095.2015.1103177
[25]Edquist, C. (2001, June). The Systems of Innovation Approach and Innovation Policy: An account of the state of the art. In *DRUID conference, Aalborg* (pp. 12-15).

Table 2 Functions of Systems of Innovation[26]

#	Function	Description
F1	Knowledge development & diffusion	Expansion and intensification of the knowledge base of the innovation system, dissemination of knowledge among actors in the system, creation of new combinations of knowledge
F2	Entrepreneurial experimentation	Designing of business models for emergent technologies and knowledge, practices of uncertainty reduction through experimentation with new technologies, applications, and strategies
F3	Market formation	Creation of a space or an arena in which goods and services can be exchanged between suppliers and buyers. Includes processes related to definition of demand and choices, positioning (pricing, segmentation) of products, regulation of standards, and the rules of exchange.
F4	Influence on the direction of search	Processes that influence the direction of research of firms and other actors; that is, which technologies they explore, which problems or solutions they choose to invest in, where they channelize their resources from, etc.
F5	Resource mobilization	Processes by which the system acquires resources required for innovation. The resources could be financial, human resources (workforce and capabilities), complementary assets such as infrastructure, etc.
F6	Legitimation	Mechanisms by which an emergent technology, its developers, and the TIS in question attain regulative, normative, and cognitive legitimacy as viewed by the concerned stakeholders.
F7	Development of positive externalities	Creation of 'system-level utilities (or resources), such as pooled labour markets, complementary technologies, and specialized suppliers, which are available also to system actors that did not contribute to building them up

Table 3 correlates the four types of resources to the innovation system's functions. Although the functions approach was initially developed for the analysis of TISs, the concept of a functional approach is also widely used for other systems of innovation approaches. The various SI approaches have a 'shared understanding' of the basic functions[27].

Table 3 How the four types of resources relate to the functions of innovation systems[28]

Resources	**Function in TIS**	**Description**
Knowledge	*Knowledge development*	Activities contributing to create new technological knowledge and competencies. Knowledge creation can relate to different types of knowledge (e.g. scientific, technological, production, market, logistics and design knowledge) and there can be different sources of knowledge development (e.g., learning by searching, learning by doing).
	Knowledge diffusion	Activities promoting exchange of information among the actors in the innovation system (e.g. learning by interacting, and learning by using in networks).
Markets	*Market formation*	Activities that create protected spaces for the new technology, helping to establish new market segments. Examples are policies that lead to the creation of competitive advantage by favourable tax regimes or minimal consumption quotes.
Financial & human resources	*Resource mobilization*	Activities that mobilize human and financial resources to the innovation process. Examples are funds for long term R&D programmes or to allow testing of new technologies in experiments.

[26]Adapted from Bergek et al., (2008)
[27]Johnson, A. (2001, June). Functions in innovation system approaches. In Nelson and Winter Conference, Aalborg, Denmark (pp. 12-15).
[28]Based on Binz et al. (2016), Hekkert et al. (2007) and Bergek et al. (2008).

Legitimacy	*Development of external economies*	External economies regard the degree to which other interests benefit from the new technology. One example is the creation of development benefits, such as jobs, business opportunities, increased energy access and reduced air pollution.
	Creation of legitimacy or counteracting resistance to change	Activities that embed a new technology in existing institutional structures or adapt the institutional environment to the needs of the technology – e.g., a change in regulations in the energy sector that will introduce the possibility for decentralized electricity generation. Activities that allow a new technology to become accepted by users, often despite opposition by incumbent interests. This also relates to development of external externalities. As more actors benefit from the new technology, "winning coalitions are created", which help sustain public and political support[29]
Coordination – not included in any of the four resources		
	Guidance of the search	Activities within the innovation system that contribute to expectation management and provide a direction to technological change, by positively affecting the visibility and clarity of specific wants among technology users. Often an interactive process of exchanging ideas between technology producers, technology users, and other actors. This helps to reduce uncertainties and overcome deadlocks when some actors do not take action until they are certain that complementary investments will be undertaken by other parties.

It should be noted that while we use the NSI framing for the analysis here, the above resources and functions align quite well with the "transformative change" framing proposed elsewhere[30] and its key dimensions of "anticipation, experimentation, participation, and directionality".

2.3 Our approach

Since innovations are dynamic processes, static descriptions of SI characteristics or **structural components** (actors, institutions. interactions and technologies) cannot fully explain the determinants and evolution of innovation systems[31]. A functional evaluation is necessary to identify and assess the innovation system's achievements, failures, and gaps or barriers. The extent to which these functions can be performed, depends on whether the structural components are present and of sufficient quality: a system's underachievement is directly related to absences or weaknesses in its structural components[32]. Functions cannot be influenced without changing the structural components of the system; they are interrelated.

Enhancing the understanding of the drivers and gaps in national systems (or initiatives situated within NSIs) in this compilation is therefore based on a 'structure-function analysis', as explained below. Table 4 illustrates how the functional analysis of an innovation system mentioned above in light of its structural components reveals the system's strengths and deficiencies (or missing links).

Table 4: Structure-function analysis[33]

Structural component	Systemic problem (Weakness)	Type of problem (weakness) related to

[29]See e.g., Meckling J, Kelsey N, Biber E, Zysman J. Winning coalitions for climate policy. Science. 2015 Sep 11;349(6253):1170-1. doi: 10.1126/science.aab1336

[30] Schot, J., and W. E. Steinmueller, 2018, Three frames for innovation policy: R&D, systems of innovation and transformative change, Research Policy, Volume 47, Issue 9, 2018, Pages 1554-1567, ISSN 0048-7333, https://doi.org/10.1016/j.respol.2018.08.011.

[31]Hekkert et al., (2007)

[32]Wieczorek, A. J., and Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and public policy, 39(1), 74-87.

[33]Wieczorek and Hekkert (2012)

Actor (for F1 to F7)	Absence of relevant actor/s	Presence/absence
	Absence or inadequate capabilities in the actor/s	Capability
Institutions (for F1 to F7)	Absence of required/relevant institutions	Presence/absence
	Absence or inadequate capabilities in institutions	Capability
Interactions (for F1 to F7)	Absence of interactions between relevant actors and organizations (due to distance, lack of trust, lack of capabilities, divergent goals, etc.)	Presence/absence
	Inadequate quality or intensity of interactions (too strong, too weak)	Quality or intensity
Technology (incl. physical artefacts, knowledge setups, financial infrastructure, etc.) (for F1 to F7)	Absence of technology, infrastructure	Presence/absence
	Inadequate quality of the infrastructure	Quality

The absence or deficiency of functions or lack of synergy between functions denote 'weaknesses', 'barriers', 'systemic failures', 'blocking mechanisms', etc., and pose challenges for innovation.

The following section describes how the above concepts have been applied in the analysis in this compilation.

2.4 Case study selection and analysis

The study undertakes an analysis of a selection of (parts of) innovation systems as case studies. The selection of case studies aims to highlight initiatives or systems which have successfully addressed (part of) the challenges to climate technology innovation, leading to a well-functioning system. Hence, an important criterion considered for selecting the case studies is the maturity of the initiative and the available information. Moreover, the selection of case studies has been made to ensure a balance between mitigation and adaptation technologies, and between sectors; it also ensures regional and income level representation, keeping in mind the importance of replicability of success factors and the representativeness of lessons learned. The underlying rationale for selecting the cases is to highlight good practices (across sectors, regions, and climate goals) that can strengthen processes and activities of climate-relevant innovation systems, and form a basis for cross-learning between sectors and regions.

For a comprehensive analysis of the selected case studies and recognition of good practices for knowledge sharing, the case studies cover the following broad steps:

- First, the delivery of the initiative's functions is assessed. Here it should be noted that not every innovation system or initiative can be expected to deliver on all the functions[34]. Initiatives (or systems) could focus specifically on particular stages (knowledge creation, absorption, and application) or actors of the overall innovation system.
- Second, an analysis of the contribution of the initiative in addressing the barriers to climate innovation or the missing links and strengthening of the core areas in the overall innovation system is made. Recognising that the design and implementation of the initiatives would suit national objectives the analysis will aim to pinpoint factors that made them successful that are based on the common principles for improving innovation systems at the country levels.

Recognising the role of the initiatives in strengthening aspects of the NSI to help address specific climate and development challenges of the country will allow conclusions and recommendations (cross-country learning) to be based **not only on the *outcomes* of the initiative or innovation system, but also on the design and effectiveness of the *processes* leading to those outcomes.** Therefore, in explicit terms, the analysis will look at how initiatives in the innovation system contributed to:

- Enhancing the capabilities of the relevant actors;
- Strengthening the institutional context in which the actors operate;
- Enhancing linkages between actors, and actors and the institutional settings; and

[34]Although it can be supported or complemented by other initiatives or systems.

- Catalyzing changes for knowledge production and its wider implementation, in order to achieve co-evolving goals of climate mitigation and adaptation, and sustainable development.

Given the complexity and interlinked functioning of the innovation processes and activities, attributing the final outcomes exclusively to specific initiatives can be challenging. Nonetheless, the broader context in which the innovation was embedded and which led to the delivery of particular outcomes would aid in identifying good practices.

3 Case studies

3.1 CASE: INDIA BUREAU OF ENERGY EFFICIENCY

Country	India	**Focus**	Mitigation
Scope	Energy-use sector (demand-side energy management)	**Key innovation system functions**	F1 Knowledge development and diffusion F2 Entrepreneurial experimentation F3 Market formation
Approach	Top-down	**Starting year**	2002

3.1.1 Introduction of the initiative

This case study highlights and evaluates the role of India's Bureau of Energy Efficiency (BEE) in popularizing energy conservation and efficiency practices in the Indian economy and shaping the country's innovation landscape. BEE was set up in 2002 as a quasi-regulatory[35] and policy making body at the national level to spearhead the transformation of the Indian energy efficiency market through various regulatory and promotional policy instruments.

BEE plays a crucial role in developing and deploying policies and strategies with a thrust on self-regulation and market principles and enhancing public and corporate awareness about energy conservation measures and practices spanning across economic sectors. One of the primary operating principles of BEE is to achieve active participation and collaboration of all relevant stakeholders to bring about a fast and sustained implementation of energy efficiency. The key strategies of BEE include energy efficiency standards and labelling of equipment and appliances, energy conservation codes for buildings, energy conservation norms and goals for energy-intensive industries, and awareness raising and capacity-building.

BEE is playing a crucial role in India's energy-related GHG emissions reduction and avoidance by promoting energy efficiency adoption. BEE formulates cross-cutting policies and measures at the national level to cover major energy-consuming sectors such as industry, residential and commercial buildings, agriculture, transport, etc. The implementation of energy efficiency schemes steered by BEE is estimated to have resulted in total GHG emission reductions of around 178 Mt in 2019-20[36].

3.1.2 Legislative Framework

Recognizing the relevance of energy optimization in addressing the entwined goals of energy security, energy access, and climate change mitigation, the Government of India (GOI), introduced the Energy Conservation (EC) Act[37] in 2001. The primary objective of the EC Act is to promote energy efficiency and alleviate the energy intensity of the Indian economy. In order to institutionalize the implementation of energy efficiency and facilitate the delivery of the goals of the EC Act, BEE was established in 2002 as the nodal central statutory body under the Ministry of Power. The EC Act provides the legal mandate, institutional structures, and regulatory mechanisms for BEE's policies and strategies at the national and state levels. The Act empowers BEE to organize

[35] BEE is a quasi-regulatory authority set-up by Indian Government for implementing and promoting energy efficiency initiatives within the regulatory framework of the Energy Conservation Act, 2001. BEE also functions as a policy advisory body to the central and state governments for mitigating barriers for market transformation in energy efficiency.
[36] BEE. (2021). Impact of Energy Efficiency Measures for the Year 2019-20.
https://beeindia.gov.in/sites/default/files/BEE_Final%20Report_Website%20version.pdf
[37] GOI., (2001). Energy Conservation Act 2001.
https://beeindia.gov.in/sites/default/files/The%20Energy%20Conservation%20Act%2Cchp1.pdf

policies and programmes to achieve effective energy utilization, determine and design energy utilization standards for sectors, recommend energy efficiency measures, monitor and verify energy efficiency improvements, and notify and penalize the defaulters. In addition, the Act also directs relevant state agencies and organizations to coordinate with the activities of BEE and promote energy efficiency in the states. BEE under the EC Act is also empowered to promote research and development to undertake energy conservation.

Furthermore, BEE is spearheading the implementation of energy efficiency activities outlined under the country's National Action Plan on Climate Change (NAPCC). BEE, along with other local organizations such as the Energy Efficiency Services Limited (EESL) organizes and implements flagship schemes and programmes as part of the Roadmap of Sustainable and Holistic Approach to National Energy Efficiency (ROSHANEE),[38] one of the key missions of the country's NAPCC.

3.1.3 The Indian NSI: Actors, institutions, drivers and gaps

Energy governance in India is multi-layered, due to the federal structure, and complex. A range of government actors operate in this area, interacting with a highly diverse end-user group, which diverges in terms of energy needs and incomes, user categories, etc. Actors include different ministries at the central and state levels (such as power, petroleum, coal, renewable energy, environment, etc.), public agencies (such as Central Energy Regulatory Commission, CERC; State Energy Regulatory Commission, SERCs; central and state transmission utilities, etc.) as well as private organizations (industry, etc.). Therefore, implementing any policy strategy or programme is challenging.

The Indian NSI is still emergent and fragile; actors lack capacities, access to knowledge and finance is limited, policy frameworks are weak and inconsistent, and the interaction among actors is inadequate.[39] In recent times, the policy framing in the energy sector has been predominantly driven by the twin goals of managing rising energy needs and curtailing GHG emissions from energy generation and consumption. Consequently, the Indian energy sector is undergoing a significant transformation towards renewables and enhanced energy efficiency.

Despite its merits, implementing energy efficiency in India is quite challenging.[40] Like other developing regions, market failures such as lack of awareness, insufficient access to technology and funds, high transactions costs, limited technical and institutional capabilities, perceptions of high investment risks, etc., make the process difficult.[41] Moreover, factors such as flawed energy pricing and procurement practices, non-internalization of the environmental costs, a lack of life-cycle analyses, difficulties in assessing costs and benefits of energy efficiency, considerations of rebound effects, etc., make the designing of energy efficiency policies quite tricky. Divergences in energy efficiency performance across the Indian states and industrial sectors do not help the situation either.[42]

3.1.4 Description of the initiatives

The following paragraphs discuss three leading programmes being implemented by BEE, resulting in significant energy savings and GHG abatement.

3.1.4.1 Standards and Labelling Programme (S&L)

BEE launched its Standards and Labelling (S&L) programme in 2006 to promote appliance energy efficiency and provide consumers with an informed choice about the energy and cost-saving potential of energy-efficient (star-labelled) products. The scheme has been invoked for 21 equipment/ appliances (e.g. lights, refrigerators, etc.) so far. BEE recognized that to implement performance standards for appliances, three factors were indispensable:

- Definition of performance standards for equipment;

[38] ROSHANEE is the upgraded version of the earlier National Mission on Enhanced Energy Efficiency, NMEEE under India's NAPCC, https://beeindia.gov.in/sites/default/files/Roshanee_print%20version%282%29.pdf

[39] Rajan, Y. S. (2012). Shaping the national innovation system: The Indian perspective. The Global Innovation Index, 131-141.

40 Singh, D., Sant, G., & Chunekar, A. (2012). Improving energy efficiency in India: need for a targeted and tailored strategy. Wiley Interdisciplinary Reviews: Energy and Environment, 1(3), 298-307.

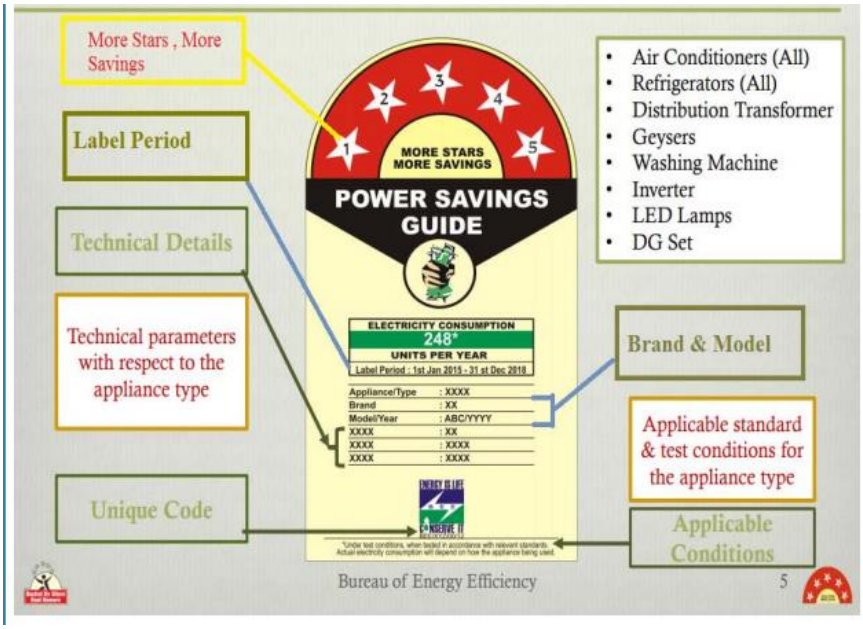
41 Sorrell, S., & O'Malley, E. (2004). The economics of energy efficiency. Books.

[42] Ministry of Power, GOI. (2019). India State Energy Efficiency Index. https://beeindia.gov.in/sites/default/files/State-Efficiency-Index-2019%20%281%29.pdf

- An assured demand and supply of products;
- A supporting testing and services infrastructure.

Regardless of the entry of multinationals such as Hitachi, LG, Philips, Whirlpool, and other big names in the Indian market, the consumer appliance product category hardly had any energy-efficient products.[43] Moreover, absence of performance benchmarking (and standardization), and prevalence of small and medium units in the appliance manufacturing ecosystem resulted in wide deviation in the operational features[44] of appliances.[45] End-users were unaware of potential climate gains and cost savings of energy-efficient appliances. However, BEE could foresee the immense potential for energy savings and GHG emission reductions from energy-efficient appliances in light of the growing appliance market in the country. In order to tap into this opportunity, BEE recognized that it was crucial to focus on four main actor groups: end-users, retailers, manufacturers, and testing and servicing professionals.

Figure 4 BEE star labelling programme: Star label[46]



A first important task was to **create a demand for energy-efficient products**. To achieve this, intensive awareness-building efforts through publications[47] (promotional materials, newspapers, magazines, books, leaflets, etc.), electronic media,[48] social media,[49] radio,[50] television, etc., were carried out. Awareness workshops, seminars, outreach programmes and capacity building initiatives were undertaken. BEE also conducted retailers' training programmes to disseminate information on the merits of star-labelled products so that the retailers can persuasively motivate the consumers to opt for efficient products. To begin with, performance standards were defined for refrigerators and air conditioners (ACs) as these were the most energy-consuming appliances in the Indian context.

After buy-in from the end-users, it was important to effectively engage with the manufacturers and create an adequate testing and servicing infrastructure for energy-efficient equipment.[51] The creation of market demand

[43] Chaudhary, A., Sagar, A. D., & Mathur, A. (2017). Innovating for energy efficiency: a perspective from India. In Sustainability-oriented Innovation Systems in China and India (pp. 57-58). Routledge.
[44] For instance, voltage settings, wattage, run-time, idle-time, energy usage patterns, etc.
[45] Chaudhary et al., 2017
[46] http://cercenvis.nic.in/PDF/BEE%20Star%20Labelling.pdf
[47] For example, BEELINE, COFFEE TABLE BOOK, Corporate Brochures, Leaflet of each programme, Bachat ke Sitare, Laghu Pustika, posters/pamphlets/ stickers, calendars
[48] Messaging through SMS/Internet to create awareness on Energy Conservation Day
[49] Facebook, twitter, youtube, etc.
[50] Radio Spots in FM: - 156 episodes of "BachatKeSitare" were broadcast on AIR FM Gold
[51] Malhotra, A., Mathur, A., Diddi, S., & Sagar, A. D. (2021). Building institutional capacity for addressing climate and sustainable development goals: achieving energy efficiency in India. Climate Policy, 1-19.

and the definition of performance standards **instilled confidence among manufacturers and spurred innovation** and eventually led to market transformation. The 'technology-neutral' nature of the S&L programme lent the manufacturers the flexibility to innovate with technologies and processes. To develop a complementary infrastructure for testing, actors and resources were created using a 'multi-pronged' strategy. Government research organizations (CPRI, etc.), private actors, academic institutions (IIT Delhi, Bombay), etc., were brought in to set up testing facilities and define protocols. Sectoral experts, manufacturers, accreditation authorities (e.g., NABL), testing laboratories, standards bodies, consumer groups, etc., were also consulted before and during the firming up of the strategy and standards.
The programme also drew on **international experiences and resources** using the technical expertise of the Collaborative Labelling and Appliance Standards Program (CLASP) and funding opportunities (engagements with the USAID, USEPA, and UNF) provided by it.[52]

S&L followed a phased approach. It started as a voluntary programme for select products, which became mandatory for several product categories once market preparedness, consumer receptivity, and market penetration of efficient appliances increased.[53] In sum, the **design and focus areas of the S&L programme was strategically planned**. The specific gaps in the innovation system were recognized early on. Efforts were focused on creating the missing actors, resources, capabilities, and institutions. And in this process all significant elements and stakeholders of the overall innovation system were looped in for effective implementation of the programme.

3.1.4.2 Energy Efficient Lighting

Two main energy efficiency lighting programmes are covered here: Bachat Lamp Yojana, BLY and Unnat Jyoti by Affordable LEDs for All, UJALA.

Bachat Lamp Yojana (BLY) was launched under the Market Transformation for Energy Efficiency (MTEE) programme to promote the large-scale deployment of energy-efficient Compact Fluorescent Lamps (CFL) to replace incandescent bulbs. At the very start, BEE recognized that the higher price of CFLs could prove to be a significant deterrent to end users and accordingly worked out an innovative business model. BLY was developed as a Programme of Activity (PoA) under the CDM,[54] and the revenue from the carbon credits was leveraged to eliminate the price difference. BLY distributed CFLs at around INR 15 to the households in exchange of incandescent bulbs. Participation by households in the programme was voluntary. To make the market transformation smooth and effective, BEE facilitated Public-Private Partnerships (PPPs) between GOI, private CFL manufacturers, and state-level electricity distribution companies (DISCOMS). Thus, BLY was designed as a win-win proposal for all.

BLY[55] was replaced by the Unnat Jyoti by Affordable LEDs for All (UJALA)[56] programme in 2014. Despite lower operating costs of LEDs and its GHG emission reduction potential, large-scale LED deployment was quite challenging because of the higher upfront costs of LEDs, limited awareness among potential users, absence of policies incentivizing LED implementation, and apprehensions of some key actors (e.g., the DISCOMS).[57] Moreover, the lack of technical standards for LED lamps and their components posed a crucial gap that needed to be addressed before their market implementation.[58] Energy Efficiency Services Limited (EESL), the organization that spearheaded the programme under the guidance of BEE, worked out a 'demand aggregation-price crash model' to mitigate some of these gaps.[59] The **business model involved lowering costs by employing economies of scale through demand aggregation and bulk procurement** of LEDs.[60] Consequently, LEDs were

[52] Malhotra et al., 2021
[53] CUTS CCIER. (2017). BEE energy star labelling program: Brief overview on implementation & success factors. CUTS Centre for Competition, Investment & Economic Regulation (CUTS CCIER).
[54] The PoA was registered at the UNFCCC in 2010.
[55] Another factor for the discontinuation of the BLY was the fall in CER prices after the weakening of the CDM post 2012
[56] Also known as LED-based Domestic Efficient Lighting Programme (DELP)
[57] The distribution companies feared that energy efficient lighting could lead to losses, however, reduction in peak load demands due to efficient lighting in situations of energy deficit helped them better manage the energy demand.
[58] Malhotra et al., 2021
[59] IBEF. UJALA. YOJANA. https://www.ibef.org/government-schemes/ujala-yojna.(accessed on May 15, 2022)
[60] EESL procured LED bulbs over successive rounds of competitive bidding, manufacturers needed to submit technical and price bids according to pre-specified criteria by EESL.

distributed to the end-users at 40% discounted prices, without subsidies.[61] Furthermore, consumers were allowed to choose to pay total cost upfront or use the 'pay as you wish/on-bill financing' programme, with the costs included as monthly instalments in the electricity bill.[62] Government networks and infrastructure were utilized for the distribution of LEDs under UJALA.[63] To define energy efficiency standards for LEDs and their parts, BEE tapped into the experience of the S&L programme. An international expert group developed the standards which were adopted by the Bureau of Indian Standards (BIS).

Figure 5 Operating Model of UJALA Programme[64]

Furthermore, all relevant actors across the value chain (manufacturers, state utilities, local vendors, distributors, etc.) were given responsibilities, depending on their capabilities, and were directed to work according to **standard templates and processes** organized by the EESL.[65] In order to create early markets and build the confidence of the actors engaged in the process, BEE funded pilot installations of street lighting applications in selected regions. The resulting cost and energy savings encouraged stakeholders, including state government regulators, to have a buy-in in the programme and to scale it up further. The choice of street lighting as the focus of the pilot interventions had strategic relevance. Similar to the S&L programme, BEE **kick-started the programme with low-hanging fruit**, with the potential for maximum energy savings per investments or effort required. Beyond cost optimization and large-scale deployment, UJALA also managed to create an ecosystem for LED manufacturing ('localization of LED manufacturing')[66] in the country.[67]

3.1.4.3 Perform Achieve and Trade (PAT) Mechanism

The Perform Achieve and Trade (PAT) mechanism was launched in 2012 under the NMEEE as a market-based strategy to promote energy efficiency in industrial sectors in India. BEE is the overall regulator of the programme, with EESL as the implementing and monitoring agency. In spite of the availability of appropriate technologies and the potential for energy conservation and cost savings in the medium to long-run, energy efficiency strategies have not been very popular in the Indian industry. This has been due to a lack of information, access

[61] IEA. 2017. "India's UJALA Story." International Energy Agency (IEA). https://eeslindia.org/img/uajala/pdf/UJALA_Case_Studies_1.pdf
[62] IBEF. UJALA. YOJANA (2022)
[63] Chunekar, A., Mulay, S., & Kelkar, M. (2017). *Understanding the Impacts of India's LED Bulb Programme," Ujala"*. Prayas (Energy Group). https://www.researchgate.net/profile/Sanjana-Mulay/publication/349924839_Impact_of_India's_large-scale_LED_bulb_program/links/604789f492851c077f297fcb/Impact-of-Indias-large-scale-LED-bulb-program.pdf
[64] https://www.asiacleanenergyforum.org/wp-content/uploads/2017/06/3_SUCCESS-STORY-SCALING-UP-ENERGY-EFFICIENCY-AN-INDIAN-EXPERIENCE.pdf
[65] Malhotra et al., 2021
[66] Malhotra et al., 2021; Chunekar et al., 2017
[67] Mir, D. A., Doll, C. N., Lindner, R., & Parray, M. T. (2020). Explaining the diffusion of energy-efficient lighting in India: A technology innovation systems approach. Energies, 13(21), 5821.

to funds for initial investments, long payback periods, the absence of incentive structures, etc.[68] The national energy management ecosystem also lacked qualified manpower to monitor and verify energy consumption in industrial units at a large scale. The PAT scheme was introduced to address some of these barriers and establish a 'methodology-driven', robust, transparent, and flexible mechanism to **incentivize the implementation of industrial energy efficiency** in a cost-effective manner.[69]

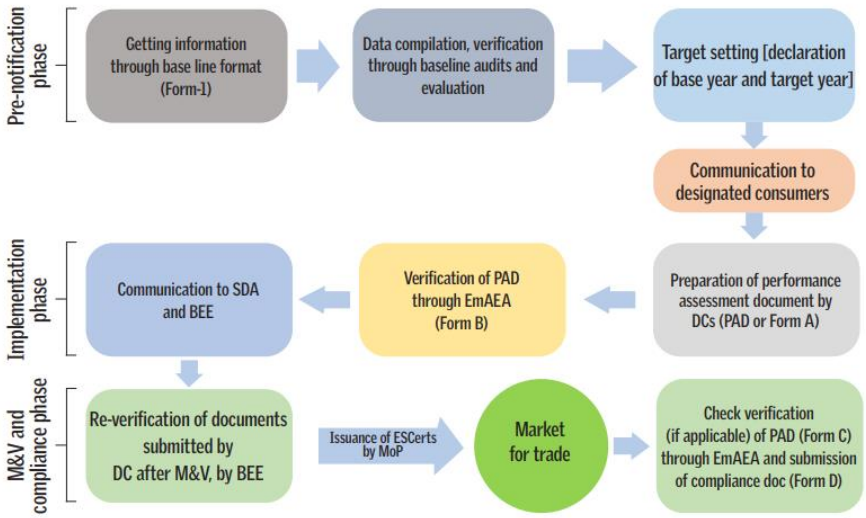
Under PAT, industrial units from energy-intensive sectors are selected, and unit-specific baselines and mandatory energy savings targets are defined. Sectoral baselines or similar approaches are considered problematic as the Indian industrial units within a sector display a wide range of efficiency levels[70]. Also, setting too strict energy standards could lead to units shutting down, whereas too lenient standards could facilitate the continuation of underperformance by industries. Penalties are levied on non-compliance, while tradable energy saving certificates (ESCerts) are issued on over-performance, i.e. being more efficient than required under the standard. The market determines the prices of ESCerts, and over-performers can sell their certificates to those that do not comply with the standard. The 'technology-neutral' approach of BEE provided the required flexibility to the facilities to choose a pathway for energy conservation that was most suitable for them.[71]

The approach meant that BEE required plant-level energy data inventories to define baselines and energy-saving targets. To achieve this task, BEE engaged third-party energy auditors, most of whom were already working for BEE, and **conducted rigorous consultations with industry participants**. The industry consultations also helped shape the finer aspects of the mechanism's implementation. BEE created a Knowledge Exchange Platform to facilitate interaction among industry actors and in turn, peer-to-peer learning about best practices and technologies.[72] Furthermore, the PAT mechanism needed technically trained and accredited energy auditors, verifiers, and managers, for which BEE, along with EESL and other ESCOs, undertook an extensive training and accreditation to **create a pool of energy specialists.**[73]

PAT has been designed as a **dynamic and evolving scheme**, with each implementation cycle redefining the designated sectors/units and the energy consumption norms.[74] Over the course of the PAT cycles, the industrial units matured and felt incentivized to upgrade their capacities and infrastructures to achieve maximum energy savings. While PAT implementation was not without flaws,[75] it helped steer the industry towards efficient operations and created a technically trained human resources base to measure and monitor energy consumption in the industry.[76]

[68] Bhandari, D., & Shrimali, G. (2018). The perform, achieve and trade scheme in India: An effectiveness analysis. Renewable and Sustainable Energy Reviews, 81, 1286-1295.
[69] Chaudhary et al., 2017; Bhandari and Shrimali, 2018
[70] Chaudhary et al., 2017
[71] Chaudhary et al., 2017
[72] Bhandari and Shrimali, 2018
[73] Chaudhary et al., 2017; Malhotra et al., 2021
[74] Sarangi, G. K., & Taghizadeh-Hesary, F. (2020). Unleashing market-based approaches to drive energy efficiency interventions in India: An analysis of the Perform, Achieve, Trade (PAT) Scheme (No. 1177). ADBI Working Paper Series
[75] e.g. in target definition, baselines, lack of clarity and consistency in methodology.
[76] Bhandari and Shrimali, 2018; Sarangi and Taghizadeh-Hesary, 2020

Figure 6 Activity flowsheet of the PAT scheme[77]



3.1.5 Assessment of the initiatives

A structure-function coupled assessment was done for the programmes discussed above to underscore how the initiatives have facilitated the delivery of systemic functions by enhancing the structural components of the Indian innovation system in the energy efficiency domain and eventually strengthening the country's NSI with respect to the overall energy use sector.

BEE is well aware of the strengths and weaknesses of the Indian energy innovation space. So, although the various programmes were designed to focus on enhancing the strengths and closing the gaps in line with the objectives and context of the intervention, BEE used some elementary strategies across its interventions. These common strategies were essentially some of the very determining systemic functions (particularly in the Indian context) that support crucial stages or structural elements of the innovation process, as discussed below.

Knowledge development, diffusion, and network impacts: All BEE programmes have a significant impact on knowledge generation, diffusion, and capacity building. Depending on the design and focus of the initiatives and the prevailing deficiencies in the innovation system, BEE ensures that relevant actors' technical, institutional, political, and financial capacity building (including the creation of new/trained actor groups) is at the core of the implementation plan.

BEE recognizes that innovation is a systemic affair: i.e., pockets of capable actors and institutions interspersed by actors/institutions lacking adequate capacities - a common feature in a developing country context - could undermine the overall effort. BEE also acknowledges that capacities are 'distributed across a range of actors and networks' comprising the innovation system. It is therefore critically important that effective interaction and exchanges between the various components of the system[78] take place along the innovation cycle. For example, BEE takes special effort to engage relevant research organizations and academic institutions to leverage their domain expertise besides providing a sound, scientific basis and backing to its interventions. The creation of the Knowledge Exchange Platform under the PAT mechanism or the PPPs in BLY are other examples of such interaction between components and actors along the cycle.

[77] N. Kumar Yadav, S. Kannappan, S. Ramanathanand S. Arora, 2021, Perform, Achieve and Trade (PAT) Scheme in Thermal Power Plants: A Critical Analysis, Centre for Science and Environment, New Delhi, see: file:///C:/Users/Admin/Downloads/http___cdn.cseindia.org_attachments_0.39290800_1638522872_pat-of-tpp-report.pdf

[78] Primarily policymakers, technology developers and manufacturers, industry and household users, financial agencies, knowledge institutions, etc.

Most of the initiatives have built-in procedures for monitoring and verifying outcomes. This supports a sustained delivery on the goals, in addition to helping to pinpoint missing links or gaps in the system. BEE acknowledges the cumulative nature of knowledge creation and capacity building and ensures that all relevant actors and networks have ownership. The strategies have a forward-looking and flexible outlook and adapt to the changes in the policy, market, and technology domains in the country and beyond.

Entrepreneurial experimentation and market formation: To improve risk perceptions that affect the willingness of actors and to seek their buy-in to the programmes, BEE has worked out innovative governance and market models using no regret/win-win approaches[79]. For instance, the design of BLY or UJALA was such that every actor engaged in the programme felt incentivized: end-users and manufacturers could foresee the energy savings and the financial gains. The UJALA programme worked out a 'demand aggregation-price crash model' to bridge the price gap between LEDs and conventional lighting. The end-users, over and above the savings in their electricity bills, got the LEDs at 40% discounted prices, and had the option to make the payment in one go or over time. In the street lighting programme, pilot or demonstration initiatives were run to instil confidence among stakeholders. BEE generally followed a technology-neutral approach in situations that demanded product or process-level innovations by manufacturers. This provided manufacturers the flexibility to opt for energy conservation pathways most suitable to them. Such innovations in governance or market structures alleviated the stakeholders' risk notions and facilitated the formation of early markets and, eventually, market transformation.

Resource mobilization and development of positive externalities: For each of its initiatives, a crucial element of BEE's strategy was to identify the factors which could determine the effectiveness or the scale of the intervention and ensure that a complementary, system-level infrastructure[80] is developed. For instance, the development of energy auditors/managers in the PAT mechanism, performance standards for LEDs or appliances (for UJALA and S&L respectively), or testing facilities for the S&L programme, etc. were unambiguously aimed at making sure that an enabling, complimentary ecosystem is generated to implement the programme in a robust, sustained and effective manner. Furthermore, BEE ensures that each programme is backed by the right kind of institutional framework, in the form of policies and regulations to provide direction to the energy efficiency initiatives, systems and procedures to measure, monitor and verify energy efficiency, coordination between different policies and governance structures, and leveraging multilateral and bilateral policy structures and collaborations.

BEE also taps into international expertise, experience, and (technical and financial) resources to enhance the effectiveness and reach of its initiatives. International experiences related to implementation schemes, market models, regulatory structures, etc., have not been copied, but have been adapted to suit the Indian realities on the ground.

Legitimation: BEE followed two fundamental strategies to develop credibility and legitimacy for its programmes. First, most of the BEE programmes started as voluntary initiatives. After achieving a certain degree of consumer receptivity and market preparedness, voluntary standards were made mandatory with a broadened scope. Second, BEE's choice for specific sectors or interventions early on was not incidental, but the result of strategic thinking on minimising risks and maximising gains with limited efforts). From the very start, BEE recognized the need for a nuanced understanding of energy consumption patterns in the country and the energy efficiency improvement potential in different sectors and applications. Accordingly, given limited resources and capabilities, BEE prioritized its efforts and assets towards interventions that could accrue maximum energy savings and GHG emission reductions ('biggest bang for the buck'). This was for instance based on analyses of the largest energy-consuming sectors and activities (industry, households), as well as those with the highest growth rates (e.g. electricity-using equipment in households, such as AC, fans, appliances). As a result of BEE's strategic prioritization and design of energy efficiency interventions (along with other factors), between the years 2011 to 2019, the country's energy intensity has decreased from 65.5 toe/INR to 55.5 toe/INR crore, and annually 178 Mt CO_2 emissions have been reduced (AEEE, 2021[81]).

Table 5 below presents the summarized findings of the structure-function coupled analysis of BEE as an organization.

[79] Cost-effective or low-cost strategies with climate gains and other co-benefits without any hard trade-offs with other policy objectives, etc.
[80] knowledge infrastructure, financial infrastructure, physical infrastructure
[81] https://aeee.in/wp-content/uploads/2021/05/India's-Energy-Efficiency-Landscape-Report.pdf

Table 5: Structure-function-coupled analysis of BEE's initiatives

Function		Structural element	BEE's interventions
F1	Know-ledge develop-ment and diffusion	Actors	• Awareness-building programmes created an informed user base for energy efficiency • 'Technology-neutral' nature of the programmes lent innovative flexibility and promoted innovation by manufacturers
		Institutions	• Energy saving targets, performance standards for appliances, LEDs, etc., created much-needed institutional backing for promoting energy efficiency and healthy competition in the market • Design of the institutions[82] was iterative, meaning that standards were periodically revized/upgraded, going from voluntary to mandatory
		Interactions	• Trust building between actors facilitated interactions/learning between all relevant actors in value chain, leading to network impacts • Respective capabilities of different actors were utilized (e.g. academic and research institutes were engaged in definition of standards for S&L; distribution companies infrastructure was used facilitate distribution of LEDs in UJALA; energy auditors were engaged in the creation of energy data inventory in PAT, CLASP was brought in S&L to define standards, mobilize international funders, etc.) • Actor interactions facilitated by BEE promoted knowledge diffusion, peer-to-peer learning, and promotion of best practices • Specific Knowledge Exchange Platforms were created for shared learning • Foreign expertise and resources were also looped in (e.g., CLASP, US EPA, US AID, etc.) • PPPs were formed to minimize risks and capitalize on the respective capabilities of different actors (e.g. UJALA)
		Infrastructure	• Complementary infrastructure was created (e.g. testing/services infrastructure for S&L, human resources, energy auditors for PAT; retailers training programmes for S&L, etc.) • Energy data inventories were created as part of the programmes (e.g. PAT), helping in designing future interventions in a more informed and scientific manner
F2	Entrepre-neurial experi-mentation	Actors	• The 'technology-neutral' nature of the programmes lent flexibility to the manufacturers
		Institutions	• Phased and evolutionary approach promoted experimentation
		Interactions	• Respective capabilities of stakeholders were tapped into to create rigorous, sustainable, and attractive business models (e.g., for UJALA diverse stakeholders were made to work together and each actor felt incentivized) • Foreign expertise and resources were also looped in (CLASP, USAID, USEPA, UNF, etc.)
		Infrastructure	n.a.
F3	Market formation	Actors	• Awareness raising across programmes helped in creating market demand • Innovative business models to sustain the demand-supply dynamics (e.g. PoA in BLY; demand aggregation in UJALA) • Business models were designed in a manner such that (perception of) risks are mitigated, gaps are bridged, and each actor feels incentivized (e.g., BLY, UJALA distribution models)
		Institutions	• Phased approach (first voluntary standards/limited coverage, mandatory/broader coverage over time) helped market transformation
		Interactions	• Networks between all relevant actors (e.g., in UJALA, standard bodies, manufacturers, state utilities, local vendors, distributors, etc.) created for effective implementation • PPPs between government agencies, private manufacturers, state electricity distribution companies (e.g. in UJALA) led to effective market transformation • Actor exchanges induced peer-to-peer learning and healthy competition in the market
		Infrastructure	• Use of carbon markets (e.g. BLY), demand aggregations (e.g. UJALA), innovative payment generation mechanisms (e.g., BLY and UJALA), auction mechanisms for manufacturers (e.g., UJALA) helped create supporting market infrastructure

[82] This refers to the rules or norms governing organizational and individual patterns of behaviour within the innovation system, the definition used in innovation studies.

			• Creation of complementary capabilities, systems and infrastructure helped in market formation (creation of energy managers/auditors for PAT, testing infrastructure for S&L; LED manufacturing industry for UJALA, etc.) • Protocols and standards for manufacturers and other actors participating in the value chain were defined (e.g., in UJALA), providing a basis for more systematic and monitorable interventions in the future • Use of pilot programmes to develop early markets (e.g., UJALA street lighting programmes)
F4	Influence on direction of search	Actors	• The 'technology-neutral' nature of the programme lent flexibility to the manufacturers to innovate (in processes and products) according to their preferences
		Institutions	• Definition of energy saving targets, performance standards, etc. promoted innovation and R&D
		Interactions	• Interaction among industry actors disseminated information on best practices and steered innovation and R&D
		Infrastructure	n.a.
F5	Resource mobil-ization	Actors	• Capacity building of human resources to support the programmes (e.g., energy specialists for PAT, testing and servicing infrastructure for S&L, PPPs for UJALA • Capacity of retailers upgraded to support the promotion of energy efficient equipment • Assured market gains and demand encouraged the manufactures to invest
		Institutions	• Energy savings targets, performance standards, etc. made investments by the industry/ manufacturers obligatory
		Interactions	• Interactions among (national and international) stakeholders helped in pooling human expertise and finances
		Infrastructure	• Complementary testing and servicing infrastructure was developed • Use of carbon markets (e.g. BLY), demand aggregations (e.g. UJALA), innovative payment generation mechanisms (e.g., BLY and UJALA), auction mechanisms for the manufacturers (e.g., UJALA) helped mobilize resources
F6	Legitima-tion	Actors	• Evolutionary nature, gradual tightening the programme (voluntary to mandatory) helped build credibility and legitimacy among actors
		Institutions	• The legal and political backing of the energy saving targets and EScerts made the PAT design rigorous and legitimized the interventions • Phased approach and gradual broadening of coverage of the programme helped cumulative learning and error corrections in the institutional domain and maximized climate mitigation (e.g., S&L, PAT, etc.) • Selection of focus sector/area/equipment is also strategic, particularly in the initial phase of the programmes– easy to implement, monitor and verify with maximum climate gains (e.g., focus on home appliances in S&L, large industries in PAT, lighting in UJALA)
		Interactions	• Interactions among actors helped in spreading the word on the merits of EE appliances
		Infrastructure	• Creation of complementary infrastructures (human resource and physical infrastructures) also enhanced the credibility of BEE as an organization and its programmes (e.g., PAT, S&L, etc.)
F7	Develop-ment of positive exter-nalities	Actors	• Creation of market demand enticed the engagement of manufacturers • The 'technology-neutral' nature of the programme lent flexibility to the manufacturers
		Institutions	• Definition of standards, benchmarks, targets created the institutional infrastructure for effective and ambitious implementation
		Interactions	• Interactions between technology providers, financiers, manufacturers, retailers, users, and policy makers created trust and an enabling environment to implement and scale-up interventions
		Infrastructure	• Complementary infrastructure, including skilled manpower, energy specialists, testing and servicing ecosystem, (both human resource and physical infrastructure) was created • Creation of demand and supply promoted the financial infrastructure • Implementation of programmes helped develop local manufacturing ecosystems (e.g., LED manufacturing in UJALA, energy efficient appliances manufacturing in S&L, etc.) • Institutional and policy incentives motivated actors involved

3.1.6 Role of the BEE's initiatives in India's NDC

The government, in its effort to align and consolidate BEE's initiatives with the NDC, has launched the Roadmap of Sustainable and Holistic Approach to National Energy Efficiency (ROSHANEE), which is essentially a broader version of the NMEEE. ROSHANEE includes all the current and potential interventions related to energy efficiency in various economic domains. BEE then devized a strategic plan called 'Unlocking National Energy Efficiency Potential (UNNATEE)' to fulfil its obligations under the NDC by 2030. UNNATEE includes a framework and implementation strategy in the short, medium, and long term to ascertain a straightforward linkage between energy demand scenarios and energy efficiency opportunities with the overall energy efficiency targets for the country. The implementation strategy identifies newer potential opportunities besides focusing on the ongoing programmes by BEE.

The NSI reinforced by BEE can form a stepping stone for broadening and deepening of the energy efficiency interventions in various ways. For instance, the actors already engaged in programmes such as PAT or Energy Conservation Building Code (ECBC[83]) can align their portfolios and activities with the NDC targets in a straightforward manner. As part of its current programmes, BEE has made considerable progress in strengthening the Indian innovation system, creating a favourable regulatory and policy regime, and coming up with innovative market and business models to implement energy efficiency in the country. Moreover, in sectors engaged in BEE programmes, the process of building capacities (human resources, technological capacities, industrial and supplementary infrastructures) and pooling in of resources and expertise (including international collaborations) is already at a significant level. Streamlining them further with an ambitious outlook to cover more sectoral GHG abatement opportunities could contribute extensively to the NDC.

3.1.7 Key success factors and lessons learned

BEE's experiences hold several valuable lessons with potential for emulation in similar contexts. The main lessons from BEE's story can be summarized as follows:

A tailored approach is required as innovation needs vary: BEE recognized that innovation is a complex, multi-actor, multi-level process which mandates a combination of cross-cutting activities (say at the national level) and sectorally and geographically focused (customized) strategies. Comprehensive energy efficiency initiatives aiming to cover 'all sectors and subsectors' through single policy directives yield limited results as the already limited resources get spread too thinly across target areas, resulting in unimpressive outcomes. Accordingly, although BEE is engaged in a range of technological domains and initiatives, each programme has been customized to cater to sector- or domain-specific challenges and needs. In doing so, BEE has developed a diverse set of strategies, including technology-push and market-pull strategies, rewards and penalties, loans and waivers, etc.

Bridging sector-specific gaps is key: BEE, through experience and learning, developed an intensive understanding of the failures and gaps in the Indian energy innovation ecosystem. Consequently, the Bureau's interventions have been designed to bridge those gaps and strengthen the weaker links in the system. For instance, the development of energy auditors/managers in the PAT mechanism, the performance standards for LEDs or appliances (for UJALA and S&L respectively), and the testing facilities for the S&L programme were unambiguously aimed at making sure that an enabling ecosystem is generated to implement the respective programme in a robust, sustained and effective manner.

Innovation activities need to be strategic, iterative and evolutionary: From the very start, BEE acknowledged the evolutionary nature of innovation processes. BEE's initiatives were revised and upgraded in response to technological developments, market transformations, political mandates, collaborative learning, international influences, upgrading actor capabilities, evolving user needs, etc. For instance, the S&L programme gradually broadened its scope (in terms of equipment/sectors covered) as the market matured and the scheme garnered greater acceptance by end-users. Similarly, the CFL programme under BLY was aptly replaced by UJALA as LED technology was more energy-efficient than CFLs.

[83] The **Energy Conservation Building Code** (ECBC) is an initiative being undertaken by the BEE (under the EC Act, 2001) to promote energy efficiency standards in commercial and residential buildings. ECBC was first launched in 2007 for new commercial buildings, but it has been revized and upgraded (e.g. in 2017) thereafter to include the residential sector, etc. (refer to https://beeindia.gov.in/content/buildings for more details).

BEE's choice or prioritization of the focus sectors has also been strategic. The Bureau has prioritized its efforts and assets towards interventions that could accrue maximum energy savings and GHG emission reductions ('maximum bang for the buck'). This logic has driven BEE's focus on industry, buildings, appliances, etc.[84]. Besides resource optimization and delivery of maximum gains, this approach has also helped build the implementing agency's credibility and legitimacy.

Coordination and integration of NSI elements is crucial: BEE's story highlights the role and efficacy of a coordinating agency ('system operator/aggregator') in initiatives with multiple goals (innovations for sustainability: energy saving, GHG mitigation, energy security, etc.), multiple sectors, and multiple actors. BEE as the coordinating agency assesses the domain-specific gaps, designs programmes to alleviate them, takes on board multiple perspectives of different actors, undertakes institutional framing to support the activities, facilitates interactions between actors, encourages market formation, and taps into international expertise and funds. Moreover, BEE builds on to the experiences and learnings of one programme to better design the subsequent initiatives making the process cumulative and evolutionary. As the 'system integrator' with a 'bird's-eye-view' of the overall Indian innovation system in the energy domain, BEE undertakes trust building exercize and facilitates synergistic engagement of the different structural elements (technology providers, financiers, technocrats, policy makers, end users, etc.) to develop effective networks. A deep and empirical understanding of the Indian innovation space helps BEE design innovative governance and market models that are win-win for all. Consequently, after the initial trigger and push by BEE and policy incentives, energy efficiency initiatives become self-sustainable, successful business models and lead to cascading impacts (delivery of systemic functions) in the overall innovation system.

3.1.8 Good practices for potential replication

Based on the above lessons learned from the BEE case, the following good practices can be identified that could lend themselves for replication in other countries:

- Map the NSI before designing and implementing strategies: It is crucial to obtain a deep understanding of the structural elements and functions of the sector-specific innovation system, the GHG mitigation opportunities vis-à-vis costs and technologies required at the sectoral or country level, main actor groups, the state of resources and capabilities, barriers and missing links in the innovation ecosystem, potential synergies and trade-offs with other initiatives and policy structures, and the role of international collaborations.
- Look for win-win measures: It is important to design win-win strategies (through innovative governance and market models) to ensure participation by all relevant stakeholders and minimization of the risk factors.
- Coordinate and integrate with local needs and the local agenda: It is essential to ensure that the initiative is in synergy and integrated with the overall policy framework of the country and that it facilitates the larger development and climate objectives of the region.
- Learn iteratively, be adaptive: Design learning mechanisms so that the impact of the strengthening of functions and the structural elements or a change in the characteristics (opportunities, strengths, needs, etc.) of the context in which the initiative is being implemented can lead to further strengthening in an iterative way.
- Create complementary knowledge and servicing infrastructure: In order to promote and implement technological innovations effectively and consistently (in the long term), the creation and sustenance of complementary knowledge, skill sets, and trained human resource base must be facilitated. This will also aid in monitoring, measuring, and upgrading technological innovations.
- Allow flexibility to achieve policy: This is particularly relevant in a developing country context. Where possible, the policy goals and aspirations need to be highlighted, and the stakeholders could be given the flexibility or leeway to choose or adopt the technology/means best suited to them to achieve those goals

[84] As per 2021 statistics, the industry sector accounts for the lion's share, with 41% of the total energy consumption, followed by the domestic sector with 26%[84]. Similarly, owing to near-universal household connectivity to electricity and rising incomes, the electricity consumption in the buildings sector has almost doubled in the past decade (IEA, 2021). Moreover, the energy use in buildings is primarily driven by lighting, fans, and appliance use.

(e.g. be technology-neutral). This will generate credibility for the regulator's actions, manage risk perceptions of the stakeholders, and facilitate faster attainment of the policy goals.

- Establish a clear role for a 'system-integrator' or coordinating agency: In situations where diverse stakeholders need to come together to make an intervention/innovation effective, the role of coordinating agencies or 'system operators/integrators' becomes important. Coordinating agencies with a holistic understanding of the strengths and flaws of the overall innovation system of the country can organize the actions of different stakeholders, address the system gaps, tap into the system resources and respective strengths of the actors, and maximize the network impacts.

3.2 CASE: KENYA CLIMATE INNOVATION CENTER

Country	Kenya	**Focus**	Mitigation & adaptation
Scope	Energy supply & demand, agriculture, water, waste management	**Key innovation system functions**	F1 Knowledge development and diffusion F2 Entrepreneurial experimentation F3 Market formation F5 Resource mobilization
Approach	Top-down	**Starting year**	2012

3.2.1 Introduction of the Initiative

The Kenya Climate Innovation Center (KCIC) was launched in 2012, to develop a 'cutting-edge facility' to promote innovative climate change solutions and sustainable development in Kenya by supporting the development, deployment, and transfer of locally appropriate climate and clean energy technologies.[85]

KCIC aims at both mitigation and adaptation benefits in the long term with a specific focus on renewable energy, clean water, agriculture, and energy efficiency. Initiatives targeting reductions in GHG emissions and enhanced access to clean energy lead to emission reductions while impacts on livelihoods and other socio-economic sectors augment the adaptive capacity of the local population.[86] To do so, KCIC provides incubation, capacity building, and funding to endeavours aiming at innovation in off-grid energy, renewable energy, agriculture and agribusiness, water management, commercial forestry and waste management. Accordingly, the Center delivers a mix of socio-economic and environmental outcomes, including GHG emission abatement, improved climate resilience, livelihood generation, and enhanced access to clean energy and safe drinking water. KCIC also promotes technology transfer and local innovation through private sector engagement, business model refinement, and market entry. The Center is engaged in mainstreaming SDGs and climate change in the country as one of the institutions supporting innovations in clean technology. It is estimated that through its interventions the Center has helped abate over 300,000 tonnes of GHG emissions so far.

3.2.2 Legislative framework

The Kenyan CIC was not established as a result of specific Kenyan legislation, but set up as an international initiative. The concept of the 'Climate Innovation Centers' (CICs) was developed in 2010 in the report 'Climate Innovation Centers - A New Way to Foster Climate Technologies in the Developing World', a joint effort by UNIDO, the UK Department for International Development (DFID), and infoDev, the World Bank's global partnership programme. KCIC is the world's first CIC in a global network of CICs being established by infoDev's Climate Technology Program (CTP).[87]

From its start till 2016, the Center operated as a consortium of four diverse institutions – private consultancy PricewaterhouseCoopers (PwC), Strathmore University, international NGO Global Village Energy Partnership (GVEP) International, and Kenya Industrial Research and Development Institute (KIRDI), a government institution mandated to promote industrial research and transfer of innovative technologies for social-economic development. Since then, the Center has evolved to function as a local, independent, non-profit company, having

[85] *UNIDO. The world's first Climate Innovation Centre launched in Nairobi, https://www.unido.org/news/worlds-first-climate-innovation-centre-launched-nairobi (accessed on May 10, 2022)*

[86] KCIC. About Us, https://www.kenyacic.org/about-us/ (accessed on May 5, 2022)

[87] infoDev (www.infodev.org) is a global partnership programme within the World Bank Group which works at the intersection of innovation, technology, and entrepreneurship to create opportunities for inclusive growth and job creation.

developed capabilities to fundraise its activities beyond the initial support.[88]

Aside from the KCIC, Kenya's research system is still developing, with only a draft science, technology and innovation (STI) policy (2008).[89] However, Kenya's national strategies for STI are well-defined in other legislative documents.[90] The national research policy has three main components:

- Vision 2030, which describes the country's development programme from 2008 to 2030;
- The National Science, Technology and Innovation Act 2013, which launched the national research institutions with a goal of implementing Vision 2030 and the STI plan; and
- The Universities Act of 2012, which directs universities to produce and disseminate scholarly research and promote innovation.

In light of KCIC's engagements in furthering SDGs and climate action in the country, in 2018, the Kenyan government recognized KCIC as the official implementing agency of the Promote Climate Technologies and Innovation initiative under the Kenya Vision 2030 Medium Term Plan III (MTP III, 2018-2022).[91] The Vision 2030 Delivery Secretariat signed a Memorandum of Understanding (MoU) with KCIC to explore opportunities for facilitating the implementation of climate technologies and innovation in Kenya. The primary task of KCIC under the MTP III is to support clean technology innovations.

3.2.3 The Kenyan NSI: Actors, institutions, drivers, and gaps

Kenya has a reasonably moderate science, technology and innovation capacity in Africa.[92] Of the country's GDP, 0.8% is spent on R&D; however, 47% of the domestic R&D expenditure comes from international sources.[93] In recent times, there have been efforts to bolster the NSI by creating innovation hubs, incubators, industrial parks, Centers of Excellence, technology cities, and the promotion of private sector investment in R&D initiatives.[94]

The institutional framework for research primarily comprises the National Commission for Science Technology and Innovation (NACOSTI), the National Research Fund (NRF), and the Kenya Innovation Agency (KENIA).[95] Most of the institutional framework for innovation in the country was established between 1992 and 2012.[96]

Although the national institutions have explicit visions and mandates, constrained financial capacity limits effective policy implementation, the performance of research organizations and the overall capacity of the national actors.[97] Many international research organizations[98] and intermediary organizations are located in Kenya, making the country a significant research centre in the East African region.[99] Consequently, knowledge transfer practices and intellectual property protection systems are reasonably well developed. However, these capacities are confined to a limited number of research organizations, and most research agencies and universities lack the funds and the capacity to undertake knowledge development and dissemination activities.

[88] In 2016, KCIC was registered as an independent company limited by guarantee. From September 2012 to May 2016, the Centre's activities were funded by UK AID and DANIDA through the World Bank. From June 2016 to December 2020, the Centre received financial support from DANIDA for its interventions.

[89] Ministry of Science and Technology, Republic of Kenya. (March 2008). Science, Technology and Innovation Policy and Strategy. http://www.ist-africa.org/home/files/kenya_sti-policy_mar08.pdf

[90] UKDFID. (October 2019). Assessing the needs of the research system in Kenya. Report for the SRIA programme. https://assets.publishing.service.gov.uk/media/5ef4acb5d3bf7f7145b21a22/NA_report_Kenya__Dec_2019_Heart_.pdf

[91] KCIC. https://www.kenyacic.org/2018/02/partnership-to-promote-clean-technologies-and-innovations/

[92] Kahn, M. J. (2022). The Status of Science, Technology and Innovation in Africa. Science, Technology and Society, 09717218221078540.

[93] UNESCO. 2016. UNESCO Science Report: Towards 2030. Paris: United Nations Educational, Scientific and Cultural Organization http://data.uis.unesco.org/index.aspx?queryid=68 (accessed on May 7, 2022)

[94] Yongabo, P., & Göransson, B. (2022). Constructing the national innovation system in Rwanda: efforts and challenges. Innovation and Development, 12(1), 155-176.

[95] UKDFID, 2019.

[96] Wachinga, H. (2019). National Innovation System Factors, Incentives, Culture and Institutional Linkages in Kenyan ICT Innovation Firms (Doctoral dissertation, UoN).

[97] UKDFID, 2019.

[98] The headquarters of international research organizations and think tanks such as the Royal African Society, the Pan-African University (public), the African Population Health Research Centre, the Africa Institute for Capacity Development, and the African Economic Research Consortium (private) are hosted by Kenya.

[99] UKDFID, 2019.

In terms of green entrepreneurship, a need assessment study by the World Bank revealed five main challenges, where such enterprises needed support in Kenya:

- A lack of skills, tools, and insights to translate ideas into successful businesses;
- Access to finance, including early-stage risk financing to enable high-potential start-ups to speed up their evolution;
- Access to information;
- Lack of an enabling business environment, due to the absence of a complementary policy framework or existence of unfavourable regulations on quality standards, taxation, etc.;
- Access to facilities which includes space for establishing business incubation hubs, training facilities, meeting and networking hubs (with peers, and investors), testing and demonstration facilities, manufacturing facilities, etc. [100]

Section 3.2.4 below deals with these issues in detail and further elaborates on the drivers and gaps in the Kenyan innovation system.

3.2.4 Description of the initiatives

Since its inception, KCIC has been the 'go-to institution[101]' or 'one-stop-shop solution[102]' for organizing Kenyan activities aimed at innovative climate solutions to bring about economic development and green growth. In order to foster mitigation and adaptation activities, KCIC performs two fundamental functions – providing knowledge support and mobilizing funds. Accordingly, over time, the Center evolved in line with those functions and established a specialized venture fund (Kenya Climate Ventures, KCV) for funding-related activities and a consulting arm (KCIC Consulting, KCL). The role of these two entities is further elaborated below. First, we describe the types of activities KCIC has deployed to address the challenges mentioned above. Subsequently, the working areas in which these activities are being implemented are described.

3.2.4.1 Type of activities

KCIC has been promoting green entrepreneurship since its launch in 2012,[103] providing the following:

- To address the lack of skills, tools, and insights to translate ideas into successful businesses, KCIC provides mentorships to entrepreneurs in business management, technical assistance, and customized training to impart skills needed to convert their innovations into businesses.

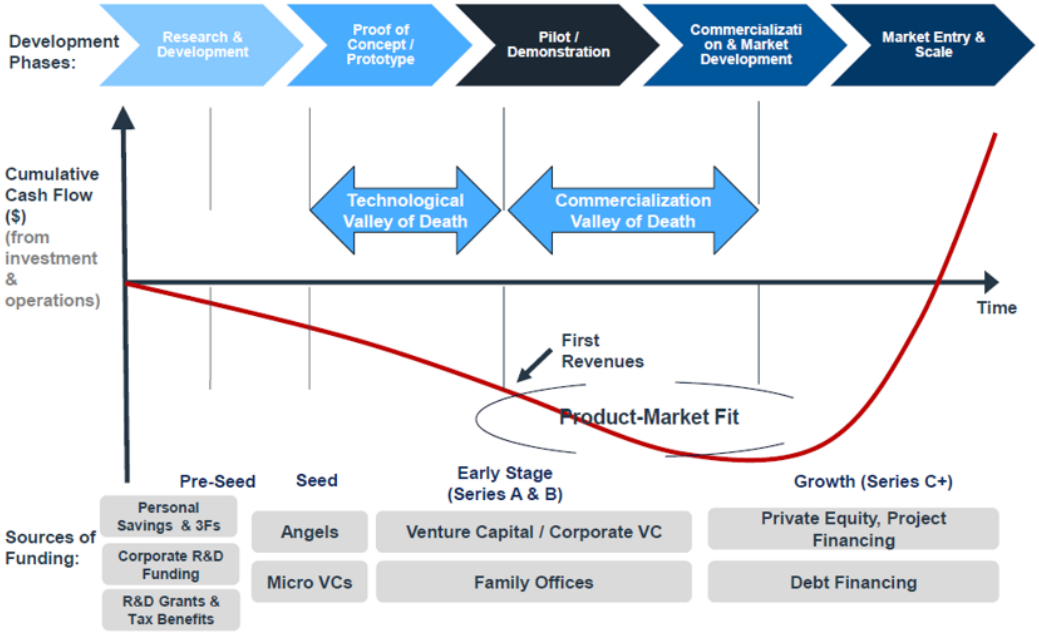
- To improve access to finance, KCIC has devised three different types of funding mechanisms for different phases in the innovation cycle:
  - Proof-of-concept grants (up to USD 50,000), as part of its incubation services.
  - Seed funding for projects with the potential to graduate from incubation towards becoming commercially viable (USD 50,000-1M) and investment facilitation at more advanced stages of innovation. The Center devises innovative business and funding models to help companies overcome the 'valley of death' funding gap. To generate seed funding, among other strategies, KCIC launched the Kenya Climate Ventures (KCV) in 2016 with an initial World Bank grant. Presently KCV is 100% owned by KCIC, which had invested US$300,000 in convertible debt in the company by 2018.[104] The combination of KCIC as an incubator and KCV as a seed funder helps address the complexities of early-stage climate innovations, which are generally low on capital, high on risks, and have long-time-horizons.[105]
  - Early-stage risk financing to enable high-potential start-ups to speed up their evolution. KCIC set up an Early-Stage Finance Mechanism (ESFM).[106] The funding for the ESFM is sourced from the KCV or other

[100] Kiraka, R. N. (2021). Green Entrepreneurship: The Case Study of the Kenyan Climate Innovation Centre. In Responsible Management in Emerging Markets (pp. 83-106). Palgrave Macmillan, Cham.
[101] Gonzalez, A., Fruman, C., Tilmes, K., & Grown, C. (2016). Trade and competitiveness global practice gender practice note: FY17-20 (No. 120480, pp. 1-37). The World Bank.
[102] KCIC. Welcome to Kenya Climate Innovation Center, https://www.kcicgroup.org/ (accessed on May 4, 2022)
[103] Kiraka, 2021
[104] Mungai, E. (2018). Impact Investing in Africa: A Guide to Sustainability for Investors, Institutions, and Entrepreneurs. Springer.
[105] Ventures, K. C. Designing an Innovative Financing Model for Early Stage Clean Technology Companies. https://documents1.worldbank.org/curated/en/381371506073998670/pdf/119909-BRI-climate-technology-program-in-brief-7-designing-an-innovative-financ.pdf
[106] The success story of Acacia Innovations is one of the most popular achievements of the ESFM. https://www.kenyacic.org/2019/06/acacia-innovations-esfm-success-story/

potential investors. The ESFM lends support in the form of debt, equity, and hybrid instruments to cover the gap faced by early-stage businesses.[107]

- KCIC increases access to information by undertaking awareness-raising programmes to disseminate information on technologies, markets, knowledge, and technology transfer mechanisms, research updates related to different business sectors, and the adoption of green solutions.
- To address the lack of an enabling business environment, KCIC lobbies government ministries and agencies to push a pro-green entrepreneur agenda. The Center taps into the expertise of innovators, research and academic institutions, etc. to undertake policy advocacy and advise the businesses on regulations and related matters.
- KCIC works with its partners to provide improve entrepreneurs' access to facilities. For instance, the Center collaborated with Strathmore University Business School to set up the business incubation hub.

Figure 7 Innovation life cycle and types of financing involved[108]



Through the above initiatives, KCIC supports green entrepreneurship at micro, meso, and macro levels.[109]

- Micro-level: Interventions at the level of individual enterprises, including capacity building, technical support, financial assistance, and mentorship to individuals and small and medium-sized enterprises.
- Meso-level: at the level of the value chain KCIC operates and supports the incubation hub, the accelerator hub, and the Seed Fund to address the funding needs of the enterprises. At this level, the Center provides business advisory on market development and policy-related strategies to businesses, investors, commercial banks, etc., to promote ideation, prototyping, and testing of products before scaling-up and commercialization. These interventions essentially aim at creating green enterprises along the value chain.
- Macro-level: at the policy and network level, KCIC collaborates with organizations such as the World Bank, international governments, the Kenyan Government, national and international academic and research institutions, etc., to provide policy advocacy and research support for green entrepreneurship. Here, KCIC engages in policy development, job creation, and building entrepreneurship culture, infrastructure, and support for research, education, etc., across multiple sectors.

[107] World Bank. 2018. InfoDev's Climate Technology Program Report for the July 2018 Steering Committee Meeting: FY18 Progress Report and FY19 Work Plan. https://www.infodev.org/sites/default/files/ctp-scm_report_2018.pdf
[108] Pepin, K., 2020, Financing a Tech Company's growth with Term Loans – It's all about Timing, see: https://kaylanpepin.com/finacing-tech-with-term-loans/
[109] Kiraka, 2021

Over the years, KCIC has marshalled more than $48 million (Sh5.4 billion) to support over 1,800 start-ups.[110] The start-ups are estimated to have generated about $32 million (Sh3.6 billion) in revenues, resulting in 25,000 indirect jobs and benefitting over 780,000 people.[111] Furthermore, KCIC undertakes special efforts to adopt an inclusive and gender-balanced approach in pursuit of its strategic goals.[112] For instance, the Center aims to support female entrepreneurs; at least 30% of its overall clientele list comprises women. Similarly, women-led agribusinesses are preferred. 60% of the total job opportunities created in the agribusiness sector are for women.[113] The Center trains, funds, and provides technical support to the women folk in sectors such as water, waste management, and commercial forestry.[114] Likewise, youth entrepreneurs are encouraged.

3.2.4.2 Working areas

The Center's working areas agri-business, renewable energy, water management, waste management and commercial forestry are each described below.

Agriculture and agribusiness

The agricultural sector in Kenya plays a very important role in terms of GDP, employment, export and as a source of industrial raw materials. However, it is hindered by smallholdership and untapped growth potential.[115] Smallholder farmers are relatively more vulnerable to climate risks such as droughts, floods, climate-induced pests and disease incidence, leading to productivity losses due to the degradation of agro-ecological systems (including soil and water).[116] Furthermore, Kenya's agriculture sector is heavily reliant on the country's bimodal rainy season.[117] Frequent droughts lead to severe crop losses, amounting to a loss of one out of every three seasonal crops. Only 1.7% of agricultural land is currently under irrigation.[118] Food and nutritional security continue to be a major concern for the country, particularly in the context of climate vulnerabilities, degrading soil quality, and the predominance of rainfed agriculture.[119]

To address some of these challenges, KCIC promotes enterprises that develop **innovative agricultural technologies and agribusiness models** that offer climate mitigation and adaptation benefits, increased productivity and diversification of production systems, and generate improved livelihood options for small-scale farmers. Some of the main agribusiness ideas supported by the Center include resilient crops/seeds, climate-friendly/energy-efficient agricultural machinery, efficient irrigation, energy-efficient food processing and climate-friendly alternatives for pesticides, fertilizers, grain drying and other field operations.[120]

[110] E Mungai. (March 31, 2022). Reflecting on my decade at Climate Innovation Centre. https://www.businessdailyafrica.com/bd/lifestyle/society/reflecting-on-my-decade-at-climate-innovation-centre-3765716 (accessed on May 10, 2022)
[111] Mungai, 2022
[112] KCIC. (May 2018). KCIC_Communication_on_Engagement_Report_2016-2018. https://ungc-production.s3.us-west-2.amazonaws.com/attachments/cop_2018/464457/original/KCIC_Communication_on_Engagement_report_2016-2018.pdf?1528868807 (accessed on May 10, 2022)
[113] Government of Kenya (GOK). (2019) Guidelines for promotion, development and management of irrigation in Kenya. Ministry of Water, Sanitation and Irrigation: Nairobi, Kenya.
[114] KCIC. https://www.kenyacic.org/2022/03/women-at-the-forefront-of-a-sustainable-future/. (Accessed on June 25, 2022)
[115] Kenya Agricultural Research Institutions, KARI. 2019. https://www.kari.org/the-major-challenges/ (accessed on May 17, 2022)
[116] Osumba, J. J., & Recha, J. W. (2019). Scoping study brief-Potential for adaptation and mitigation. https://cgspace.cgiar.org/bitstream/handle/10568/107338/CCAFS%20Briefing%20paper%20-%20Potential%20for%20adaptation%20and%20mitigation.pdf?sequence=1&isAllowed=y
[117] KARI, 2019
[118] GOK, 2019
[119] Makini, F. W., Kamau, G., Makelo, M., Mose, L. O., Salasya, B., Mulinge, W., & Ong'ala, J. (2016). Status of Agricultural Innovations, Innovation Platforms, and Innovations Investment. 2015 PARI project country report: Republic of Kenya.
[120]KCIC. Sectors that we support, https://www.kenyacic.org/sectors-that-we-support/ (accessed on May 2, 2022)

Figure 8 Some examples of KCIC supported activities: Left: hydroponics -farming without soil; Right: innovation water harvesting[121]

One of the notable initiatives of KCIC in agriculture is the **AgriBiz** project, [122] launched in March 2021. The AgriBiz project aims to enhance food security, promote manufacturing by building on the strong links along the value chain in the sector, generate livelihood for women and youth, and set up business incubation hubs[123] to provide business advisory and financing services, and modernization of the agriculture sector. The project is a collaborative initiative of KCIC, DANIDA, the European Union, the African Development Bank, and the FAO. Some of the other significant interventions of KCIC and KCV in the agriculture sector are listed in Table 6.

Table 6: Some key initiatives supported by KCIC/KCV in the agriculture, energy, and water sector

Enterprise/ Organization	Sector	Technology	Support by
Aviva Kenya	Agriculture	NERICA (New Rice for Africa) - hybrid, drought-tolerant varieties, are suitable for low-input agriculture	KCIC
Hydroponics Africa	Agriculture	Hydroponic farming- growing crops in mineral nutrient solutions in water instead of soil (saves water)	KCV
Eco Sawa	Agriculture	Organic pesticides (e.g., Dane Bio Pesticide)	KCV
Agrihouse Solutions	Agriculture	Climate-smart farming technologies, e.g., greenhouse packages, shade net houses, water harvesting reservoirs, and irrigation systems	KCV
LishaBora Hydroponics	Agriculture	Hydroponic barley fodder	KCIC
Eco-burn Char Briquettes	Energy	Char briquettes from 95% recycled agriculture waste	KCIC
Tamuwa Ltd	Energy	Biomass briquette from bagasse	KCIC
Byster Enterprises	Energy	Construction and installation of biogas plants	KCIC
Smart Cook Energy Ltd	Energy	Bioethanol-based cooking technologies	KCIC
Powerspot Kenya Ltd	Energy	Converting cooking heat into thermal electric energy	KCIC

[121] https://www.kenyacic.org/2020/12/farming-without-soil-the-big-bet-for-achieving-food-security/; https://www.kenyacic.org/2019/11/how-maji-agri-solutions-is-using-social-media-to-market-his-innovative-water-technology/

[122] KCL. Kenyan Farmers To Flourish From Sh5bn Agribusiness Fund, https://www.kcicconsulting.com/kenyan-farmers-to-flourish-from-sh5bn-agribusiness-fund/ (accessed on May 2, 2022)

[123] The project shall establish business incubation hubs in eight counties of Kenya, including Uasin Gishu, Meru, Kisii, Nyeri, Bungoma, Isiolo, Kilifi, and Lamu.

Enterprise/ Organization	Sector	Technology	Support by
Bellac Research Consultants	Energy	Distribution of home biogas system	KCIC
Arimi tech	Water/ irrigation	Sensor-based automatic irrigation system for arid and semi-arid areas	KCIC
Takawiri Craft Enterprises	Water/ irrigation	Handmade stationery and craft items from water hyacinth	KCIC
SwissQuest Water Supplies Co Ltd	Water/ irrigation	Smart prepaid water metering solutions integrated with mobile payment systems	KCIC
Aqua Rescue Ltd	Water/ irrigation	Wastewater and water treatment solutions	KCIC
Maji Milele	Water/ irrigation	Prepaid water points	KCIC
AfricAqua	Water/ irrigation	Micro-distribution centres for water	KCIC
Taka Taka Solutions	Waste management	Developing high-quality compost from organic material; sorting of wastes for recycling industries	KCIC
Ecosave Africa	Waste management	Use of microbes to recycle waste in 'eco-treat waste digester'; detoxify urine before discharging into water systems, etc.	KCIC
Adarsh polymer Ltd	Waste management	Converts plastic waste into heavy oil, carbon black, and other clean energy solutions by pyrolysis	KCIC
Chemolex Limited	Waste management	Scoop plastic out of the rivers as they drift past	KCIC

Energy

Kenya has a fast-growing energy sector, which is heavily dependent on biomass: around 68% of the country's energy needs are fulfilled by bioenergy (mainly wood).[124] It is estimated that Kenya can lose 65% of its forests for charcoal production by 2030.[125] Petroleum and electricity account for 21% and 9% of the country's total energy consumption.[126] Kenya does have significant renewable energy potential. In 2019, renewables contributed 74% of the total energy mix in Kenya.[127] The most critical challenges of the Kenyan energy sector include growing energy demand with an increasing gap between demand and supply, limited grid infrastructure, a lack of access to modern energy, over-reliance on biomass, and rising energy costs.[128]

To address these challenges, KCIC supports innovations that provide alternatives to traditional energy sources and reduce inefficient energy use in the domestic and industrial sector. Some of the initiatives focus on off-grid technologies, including off-grid solar PV, biogas, biomass, and wind energy; micro-hydro for domestic and rural mini-grid use, and bio-energy (bio-gasification, bio-diesel, biomass power, heating). Some of the specific interventions of KCIC and KCV in the energy sector are listed in Table 6.

Water and irrigation

In Kenya, water resources are scarce and characterized by a high degree of temporal and spatial variability resulting in over 80% of the land area being classified as arid/semi-arid.[129] Over 33% of the country's water resources originate outside of the country.[130] Around 15% of the Kenyan population is still reliant on 'unimproved'

[124] IEA. (2019). Africa Energy Outlook 2019: Overview Kenya. World Energy Outlook Special Report. https://iea.blob.core.windows.net/assets/44389eb7-6060-4640-91f8-583994972026/AEO2019_KENYA.pdf
[125] Onekon, W. A., & Kipchirchir, K. O. (2016). Assessing the effect of charcoal production and use on the transition to a green economy in Kenya. Tropical and Subtropical Agroecosystems, 19(3), 327-335.
[126] Takase, M., Kipkoech, R., & Essandoh, P. K. (2021). A comprehensive review of energy scenario and sustainable energy in Kenya. Fuel Communications, 7, 100015.
[127] Takase et al., 2021
[128] Takase et al., 2021
[129] USAID. 2021. https://www.usaid.gov/sites/default/files/documents/1860/Kenya_Power_Sector_report.pdf
[130] USAID. 2021

water sources such as ponds, shallow wells, and rivers, and 41% of the population lacks access to essential sanitation solutions.[131] Around 80% of the total water demand is derived from surface water, of which half is consumed for irrigation purposes.[132] Regions with sufficient rainfall to constitute productive agricultural land make up less than 20% of the country's land area.[133] Moreover, frequent droughts and floods worsen the situation with climate variability, increasing population, and escalating water demands further aggravating the problem.[134]

Over-extraction for irrigation poses threats to the sustainability of the surface water in several regions.[135] Groundwater is the primary source of water for domestic users not connected to public systems. Since agriculture is the backbone of Kenya's economy, erratic and insufficient irrigation facilities have a knock-on effect on the overall economy.[136] Despite multipronged efforts to improve irrigation coverage in the country, only 16% of the irrigation potential had been achieved by 2018.[137]

KCIC is implementing a number of initiatives to address some of the challenges discussed above. In particular, the Center supports clients working on sustainable and efficient water management technologies such as solar filtration, desalination, water harvesting, efficient irrigation, biotechnology, and wastewater reuse and recycling.[138] Building on the technical expertise of other organizations, such as the Strathmore Energy Research Centre (SERC), KCIC facilitates the training of technicians in design, construction, and maintenance of water systems.[139] SERC provides training to KCIC's clients (mainly SMEs) to install and manage smart water metering solutions, water treatment, etc. Some of the specific interventions of KCIC and KCV in the water sector have been listed in Table 6.

Waste management

In the waste management domain, the Center facilitates the implementation of innovative methods and practices for the generation, storage, collection, transport, processing, recycling, and disposal of solid and liquid wastes. Clean technologies supported by the Center include waste separation and segregation at the source, engaging local communities, reducing waste toxicity, upcycling and recycling waste into reusable products, converting waste to energy, converting waste to compost, reduction of waste generation, etc. Some of the key initiatives supported by KCIC in the waste sector have been listed in Table 6.

Commercial forestry

In the commercial forestry sector, the KCIC is empowering innovations and practices that promote responsible forestry harvesting, afforestation, and re-afforestation and discourages the felling of trees under its GreenBiz Programme. The businesses supported by the Center focus on business models that engage local communities and include marketing of trees/tree products, thrust on tree species with commercial value, sustainable forest management, use of technology for monitoring of forests, creation of livelihood options, etc. KCIC has recently launched a project called Green Economy Youth Activation Programme (GrEYAP) with support from UNDP to promote commercial forestry in the country.[140] The GrEYAP project is aligned with the broader goals of Vision 2030 and aims to address the shortfall in the wood sector in Kenya. The country lost 10% of its forest cover from 2001 to 2018 despite the growth in wood import. The KCIC is providing incubation and mentorship to the GrEYAP project.

[131] Water.org, Kenya's water and sanitation crisis, https://water.org/our-impact/where-we-work/kenya/ (accessed on May 5, 2022)
[132] USAID. 2021
[133] USAID. 2021
[134] UNESCO. 2006. Kenya national water development report: case study. A WWAP case study prepared for the 2nd UN world water development report: Water, a shared responsibility (2006). UN-WATER/WWAP/2006/12. https://unesdoc.unesco.org/ark:/48223/pf0000148866
[135] USAID. 2021
[136] Silva, I. D., Ronoh, G., Maranga, I., Odhiambo, M., & Kiyegga, R. (2020). Implementing the SDG 2, 6 and 7 nexus in Kenya—A case study of solar powered water pumping for human consumption and irrigation. In International Business, Trade and Institutional Sustainability (pp. 933-942). Springer, Cham.
[137] Kanda, E. K., & Lutta, V. O. (2022). The status and challenges of a modern irrigation system in Kenya: A systematic review. Irrigation and Drainage.
[138] https://www.kenyacic.org/sectors-that-we-support/
[139] Silva et al (2020)
[140] https://www.msn.com/en-xl/money/topstories/sustainable-commercial-forestry-that-grows-income/ar-AANe7wp?ocid=BingNewsSearch

3.2.5 Assessment of the initiatives

KCIC's interventions adopt a holistic approach vis-à-vis their working areas and they facilitate both mitigation and adaptation. This section assesses KCIC's role in the delivery of systemic functions, which have strengthened the Kenyan innovation system's structural components and contributed to the NSI. The following points discuss some of the vital systemic functions performed by KCIC.

Knowledge development and diffusion: KCIC, in partnership with other organizations, provides training and capacity building to high potential, growth-oriented, emergent businesses and investors, and local banks. The Center helps build the competitiveness of companies by providing local technologies, information on market size and prices for various technologies, the competitive landscape, market intelligence, technical and business advisory on best practices, and policy advocacy.[141]

Resource mobilization and market formation: KCIC has devised different funding mechanisms to address the financial needs of green projects (see Section 3.2.4.1). To develop and utilize human resources, the Center taps into diverse and complementary skill sets of various organizations, including government bodies, consulting firms, academic institutions, and civil society.

For market formation, in addition to strategies focussing on generating funds and addressing the needs of demand-supply dynamics, KCIC adopts a risk management approach. The Center focuses on managing both strategic and operational risks faced by its clients across various stages of the innovation cycle. The Center adopted a Risk Management Policy in 2017.[142] In specific terms, KCIC addresses:

- Investment risks through ESFM, bridging the valley of death;
- Reputational risk, undertaking trust-building between networks, actors, investors, and donors;
- Political risk, conducting policy advocacy with the government and international donors; and
- The non-availability of resources, including financial, human resources by creating appropriate networks.

These factors, in conjunction, support market formation for clean technologies.

Legitimation: To generate credibility and legitimacy for its activities, KCIC undertakes intensive stakeholder engagement with potential partners and beneficiaries while firming up the design and focus areas. Although the Center does not engage in political activities directly, it maintains good relations with the government, regulatory agencies, and other key stakeholders to facilitate the development of policies supporting technology adoption, coordinate and broker technology transfer and collaborative R&D, and international networking activities.[143] In addition, KCIC performs due diligence on its prospective clients, investors, and collaborators before making any investment or partnership decisions.[144] It also carries out client satisfaction surveys to assess its achievements and shortcomings. KCIC is also highly conscious of its reputation concerning international partners and donors, as negative perceptions may impede the uptake and performance of projects. The Center participates in international networking events/activities to increase the visibility of KCIC and associated innovators and green entrepreneurs, and climate technology in general. Another critical factor that has enhanced the credibility of KCIC is the fact that the Center is in its third funding cycle.[145]

Development of positive externalities: The above discussions highlight how KCIC promotes the creation of an enabling and complementary political, financial, and technological infrastructure by working in association with government agencies, funding organizations, technology providers, etc. This not only helps KCIC's clients but also facilitates the development of an overall enabling environment for the innovation and implementation of clean technologies. In the process, the activities of the Center generate jobs, develop skilled human resources, and create physical infrastructure for future projects.

Table 7 presents the structure-function coupled analysis of KCIC.

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[141] *InfoDev. 2016. Climate Technology Program In Brief-Number 2. The Kenya Climate Innovation Center - How it Operates and Lessons for Clean Technology Incubation. https://www.infodev.org/infodev-files/inbrief_no.2_kcic_0.pdf (accessed on May 5, 2022)*

[142] World Bank. 2018a. Kenya Climate Innovation Center Company Report and Financial Statements for the Year Ended 30 June 2018. https://documents1.worldbank.org/curated/en/339371548740230173/pdf/KCIC-FS-2018.pdf

[143] InfoDev. 2016.

[144] World Bank. (2018b). Kenya Climate Innovation Center Company Report and Financial Statements for the Year Ended 30 June 2018. https://documents1.worldbank.org/curated/en/339371548740230173/pdf/KCIC-FS-2018.pdf

[145] Kiraka, 2021

Table 7: Structure-function-coupled analysis of KCIC's initiatives

Function		Structural element	KCIC's Interventions
F1	Knowledge development and diffusion	Actors	• Training, capacity building, mentorship, customized guidance to promising, emergent projects/entrepreneurs • Provides market intelligence, business advisory to the entrepreneurs • R&D collaborations, research funding for innovation, clean technology development and diffusion • Improves fundraising capabilities of the clients • Pilots and demonstrations of new/innovative technologies (e.g., new rice varieties, etc.)
		Institutions	• Acting as an interface between companies and government agencies, facilitating the creation of complementary policy and regulatory setting to promote research, technology development, collaborations for knowledge development (e.g., quality standards, taxation, etc.)
		Interactions	• International and local collaborations, networking events, conferences, etc. to promote dissemination of knowledge and peer to peer learning
		Infrastructure	• Facilitates physical infrastructure for research and research demonstrations
F2	Entrepreneurial experimentation	Actors	• Innovative engagement/business models/funding mechanisms for different stakeholders • Livelihood generation for women, youth, etc.
		Institutions	• Acting as an interface between companies and government agencies, facilitating the creation of complementary policy and regulatory setting to promote innovative business models, funding mechanisms (e.g., quality standards, taxation, etc.)
		Interactions	• Facilitates interactions between relevant actors to promote uptake and implementation of green business projects
		Infrastructure	• Facilitates physical infrastructure for business implementation and actor engagements
F3	Market formation	Actors	• Funds (or generates funds) for green projects, developing the market supply side • Creates awareness about the merits of employing green technologies, developing the market demand side • Risk management to encourage participation by actors • Capacity building of actors to engage in the market • Livelihood generation, leading to the creation of demand • Awareness building, pilot projects to create demand for green projects/ products
		Institutions	• Acting as an interface between companies and government agencies, facilitating the creation of complementary policy and regulatory setting to innovative business models, funding mechanisms (e.g., quality standards, taxation, etc.) • Undertakes risk management (reputational risk, funding risk, political risk, etc.) for implementation of market processes
		Interactions	• Facilitating interactions between relevant actors to promote uptake and implementation of green business projects
		Infrastructure	• Creates supporting market infrastructure by developing funding mechanisms, skill trainings, allocation of physical space (office, networking hubs, etc.)
F4	Influence on the direction of search	Actors	• Recognition of priority sectors for support and funding by KCIC influences the selection of sectors/project categories by the green entrepreneurs
		Institutions	• KCIC supports/funds clients whose businesses/innovations are aligned with the country's overall policy goals • Facilitates creation of an enabling policy setting for RD&D on green projects

Function		Structural element	KCIC's Interventions
		Interactions	• Facilitating interactions between business peer, funders and recipients, etc. to guide the direction of research, learn from global and local best practices, etc.
		Infrastructure	• Creation/provision of space and facilities for research, tie-ups with research organizations, universities, etc.
F5	Resource mobilization	Actors	• Mobilizes/generates funds for projects/actors by offering different business models/funding models and management of risks across the innovation cycle • Builds capacities of actors to raise funds
		Institutions	• Engages with the government to facilitate funding and implementation of projects (e.g., taxation, funding collaborations, etc.)
		Interactions	• Works as interface between potential funders and project implementers, facilitates delivery of funding
		Infrastructure	• Provides space and setting for engagements/interactions for generation of funds
F6	Legitimation	Actors	• Conducts due diligence on clients, investors, collaborators • Conducts satisfaction surveys to assess shortcomings, failures, etc.
		Institutions	• Acts as the official implementing agency of the Promote Climate Technologies and Innovation initiative under the Kenya Vision 2030 • Engaged in mainstreaming SDGs and climate change in the country
		Interactions	• Enhances the credibility of the project/process by mediating discussions between collaborators, funders, etc.
		Infrastructure	N.A.
F7	Development of positive externalities	Actors	• Creates a pool of skilled technicians to operate and maintain green projects • Builds capacities of actors to implement projects, fundraise, negotiate with collaborators, procure technologies, etc.
		Institutions	• Acts as an interface between companies and government agencies, collaborating with the government to introduce policy and regulatory changes for the market penetration of clean technologies
		Interactions	• Assists businesses to source funding from international, local banks and venture capitalists • Created and strengthened the green business value chains by enhancing network impacts
		Infrastructure	• Creates the knowledge infrastructure by bringing in research organizations, universities, domain experts, etc. as collaborators/mentors in the project • Creates the financial infrastructure by bringing in funding organizations (international, local), venture capitalists, etc. • Helps businesses access space, facilities, equipment, etc. for setting up office, networking hubs, etc. • Enhanced the value chains, business networks

3.2.6 Role of KCIC's initiatives in Kenya's NDC

In line with the country's sustainable development agenda and its national circumstances, Kenya's National Climate Change Action Plan (NCCAP) 2018-2022 identified critical sectors for mitigation and adaptation to achieve its NDC targets.[146] For GHG mitigation, the priority sectors include energy, agriculture, forestry, industry, transport, and waste. Water, agriculture, land use, forestry, energy, health, and infrastructure have been identified as the most crucial sectors for adaptation-related interventions. So KCIC's working areas significantly overlap with the priority sectors identified by the NCCAP in line with the country's mitigation and adaptation needs.

The NCCAP recognizes KCIC as one of the relevant institutions to implement the activities outlined under the plan. The Center's interventions have a direct role in delivering Kenya's NDC. KCIC is helping the country align its long-term development vision with the strategies to address climate change issues at appropriate levels (individual/enterprise, value-chain, and network levels). The Center is building actor capabilities, promoting green innovation across sectors, mobilizing climate finance, enthusing the private sector to engage in green projects, creating livelihood options, and supporting policy implementation. KCIC, in association with other organizations, is undertaking initiatives to generate climate finance from the local private sector.[147] Kenya expects to source 87% of its climate finance needs from international support and the remaining from local actors.[148] As such, the activities of KCIC will contribute to achieving the NDC.

3.2.7 Key success factors and lessons learned

Lessons that can be drawn from KCIC's experience can be summarized as follows:

Organizations need to evolve and diversify with time to achieve their ultimate goals: Although initiated through external support, CICs are designed to function as ecosystem support providers and are expected to evolve, expand and diversify through learning-by-doing and eventually develop into self-sustaining, autonomous enterprises. KCIC is a successful example of this. The Center started as a consortium entirely funded by international actors, but as the Kenyan innovation system matured and KCIC's initiatives helped make green entrepreneurship popular in the country, the Center diversified correspondingly. The Center responded to the evolving needs of the Kenyan NSI by creating a specialized entity (KCIC Consulting) for providing hands-on mentorship and guidance to the emerging green businesses and a venture capital fund for addressing the investment needs of the entrepreneurs and enhancing the effectiveness of the impact investment. Moreover, the Center developed the capabilities to move beyond exclusively relying on foreign funding, generating alternative funding sources.

Collaborative, multi-actor partnerships crucial for effective climate action: KCIC demonstrates a robust consortium model involving different organizations from various sectors. The collaboration allows KCIC to leverage extensive and specialized local as well as international knowledge, skills, and experience to create an enabling environment for implementing clean technology innovation. KCIC also partners with specialized agencies for specific projects. The public-private, multi-actor partnership lends credibility to the organization and enhances the quality of the services provided by the Center to its clients, particularly sector-specific advisory and assistance.

Funding models need to be designed for the specific sector and phase of the innovation cycle: The financing needs of an innovation project depend on its sectoral focus, the project goals, the risk perception of the implementers, and the phase of the project in the overall innovation cycle. Accordingly, to customize the financial support to the innovation projects based on their specific requirements, KCIC has devized different and innovative funding mechanisms. The various funding tools help address not only the investment needs but also alleviate the technological, political, and reputational risks associated with the projects. Another critical lesson

[146] Government of Kenya (2018). National Climate Change Action Plan (Kenya): 2018-2022. Nairobi: Ministry of Environment and Forestry. https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2018/10/8737.pdf

[147] KCIC. https://www.kcicgroup.org/the-4c-kenya-sustainability-conference/ (accessed on May 5, 2022)

[148] Government of Kenya. (December, 2020). Kenya's first NDC (Updated Version). Submission of Kenya's Updated NDC 24th December 2020. https://unfccc.int/sites/default/files/NDC/2022-06/Kenya%27s%20First%20%20NDC%20%28updated%20version%29.pdf

from KCIC's experience is the combination of incubation and accelerator funding mechanisms which help address the many of the funding needs of clean technology businesses.

Full integration with host country development objectives needed for effective outcomes: KCIC's strategic outlook, focus sectors, and specific activities are entirely in sync with the long-term sustainable development objectives and economic priorities of the host country. For instance, agriculture, the mainstay of the Kenyan economy, is one of the priority sectors of KCIC. Similarly, since Kenya is a water-stressed country, KCIC undertakes interventions to better manage and utilize water resources. This synergy not only lends credibility to the activities of the Center but also helps leverage the technical expertise and technological and financial resources received/generated from the external and local sources to achieve the country's overall goals. It also makes it easier for the government to recognize KCIC's contributions and facilitate its functioning.

Local actors' engagement at the design stage is crucial for effectiveness: This is the logic behind setting up of tailor-made CICs in different countries. The approach and strategies of KCIC are tailored to address the gaps in the Kenyan NSI in relation to climate technology and focus on promoting sustainable development in the country. Emulation of KCIC's model in other country contexts may not generate similar results. Impressed by the success of the Center, its consortium model was emulated in Ethiopia, but this did not generate the intended results as the actors who were to implement the initiative did not participate in the design of the Center. Thus, besides building on the external support, it is crucial to leverage the expertise and experience of the local actors so as to come up with practical and compelling arrangements. This also lends legitimacy to the actions of the CIC, as evident in the case of KCIC.

Effective interaction among local actors is vital for peer learning: Before engaging in any project, KCIC undertakes an intensive analysis of market barriers, issues in the value chain, and high-impact opportunities for innovation. For this purpose, rigorous consultations are conducted among the stakeholders, domain experts, regulators, etc. The business model designed as a result is not only crucial for generating impacts on the ground. It also results in peer-to-peer interactions that help build collaborations, generate climate finance, disseminate business ideas, business models, best practices, etc. The enterprises learn the most when they interact with their peers and similar industries at comparable stages of business development.

Need for effective networking between the CICs: Although CICs ought to follow a tailored approach, interaction among the different CICs is crucial for sharing best practices, forging partnerships, and drawing lessons from other countries' experiences. A peer-learning event was organized in 2019 between the representatives of CICs from Bangladesh, the Caribbean, Egypt, and Ghana.[149] The closed group interaction between the CICs helped build solidarity between the participants and facilitated exchange of learnings regarding challenges to innovation and their solution processes. However, such interactions between the CICs are not a regular phenomenon. There is as yet unused potential for interactive learning between CICs.

CICs represent an example of an international collaborative initiative to leverage global capabilities to address local climate needs. It is not only about collaborations between developed and developing countries. It also aims at generating networks and partnerships between developing countries or the various CICs to bolster climate-relevant innovations.[150] Effective networking between the CICs could foster exchange of learnings, practices, and technologies and also expedite and scale up the deployment of clean, climate-relevant technologies.

International institutions and collaborations can help build local institutions for effective climate action: The success of KCIC demonstrates the complementary role of international support in building local capabilities for climate-relevant technology innovation. Moreover, it also shows that collaborations, interactions, and capacity-building efforts should not be limited to government-to-government exchanges. The international facilitation process should also engage local businesses and other relevant stakeholders for effective and long-term outcomes. KCIC's experience illustrates that international institutions (including multilateral development

[149] CBIN sponsored a weeklong learning event for CICs in February–March 2019. Staff from four CICs—Bangladesh, the Caribbean, Egypt, and Ghana—convened in Ghana to learn about each centre's programme offerings and share best practices to improve operations. https://www.infodev.org/sites/default/files/ctp-scm_report_2019.pdf

[150] Sagar, A. D., Bremner, C., & Grubb, M. (2009, November). Climate Innovation Centres: A partnership approach to meeting energy and climate challenges. In Natural Resources Forum (Vol. 33, No. 4, pp. 274-284). Oxford, UK: Blackwell Publishing Ltd.

organizations) can help in three main ways. First, they can foster incubation and acceleration of technology; second, they can serve as an interface between the local actors and potential funding and technological resources; third, they can stimulate policy and market actions at the local level to create an enabling ecosystem for climate action. Where local actors lack the capability or the understanding to design effective strategies, international support can help identify the missing links in the NSI, design customized strategies, etc. In the process, the international actors can provide funding, technical and policy support, after which the local actors can operate independently.

3.2.8 Good practices for potential replication

The above lessons learned lead to the identification of the following good practices that might be replicable in other countries:

- Use international collaborations to develop local capabilities and resources: International partnerships and exchanges can be used to develop local technological, financial, political, and human resources such that reliance on international support can be brought down over time. Local actions should be aimed at using international support to create an enabling ecosystem for climate action in the long term and not be limited by a project-based mode of operation.
- Evolve and diversify through learning-by-doing: International funding and guidance should be used to kick-start an initiative. However, organizations should develop their capabilities and expand their intervention areas to become independent and effective entities with sustained relevance in response to the evolving characteristics of the local context.
- Design innovative, customized and flexible funding frameworks: Device funding models to suit the stage, scope, and risk perception of the innovators/firms. Complement the funding schemes with enabling policy and financial regimes for effective and sustained outcomes.
- Focus on market creation for climate technologies: For a mature and effective ecosystem for green entrepreneurship, policies, market structures, and actor capabilities should be directed towards creating sustained demand and supply dynamics for clean technologies.
- Engage both public and private sectors: Ensure the participation of diverse stakeholders to address the complexities and uncertainties associated with the innovation processes. This will also help in tapping into the different capabilities and skill sets of various actors.
- Integrate the goals of climate initiatives with the local policy goals and socio-economic priorities: Synergies with local objectives will help in enhanced participation by stakeholders and minimize risk perceptions. This includes issues such as gender parity, employment for youth, etc.

3.3 CASE: DISASTER RISK REDUCTION IN HAITI

Country	Haiti	**Focus**	Adaptation
Scope	Disaster risk reduction in all sectors	**Key innovation system functions**	F1 Knowledge development and diffusion F4 Guidance of the search F5 Resource mobilization F6 Legitimation
Approach	Top-down and bottom-up	**Starting year**	2001

3.3.1 Introduction of the initiative

This case study will look at Haiti, a small island developing state (SIDS) in the Caribbean highly vulnerable to the impacts of climate change, and how it aims to reduce the risks associated with natural disasters. Haiti has been hit by many natural disasters throughout its past. From 1900 to 2010, the country was hit by 59 natural disasters, including cyclones, tropical storms, heavy flooding, droughts, and earthquakes.[151] It is one of the world's most affected countries in terms of economic losses from natural disasters, amounting to 17.5% of GDP over the past 20 years.[152]

The 2010 earthquake alone resulted in the loss of about 230,000 lives, the displacement of two million people[153] and hampered the country's development: damages amounted to 120% of Haiti's GDP, with the country falling from ranking 145th in the UN Human Development Index (HDI) just before the disaster to 168th in 2013.[154] The earthquake also undermined human capital and infrastructure within government: up to 20% of federal employees were killed or injured and around 25% of public buildings were devastated according to estimates.[155] Damages from Hurricane Matthew in 2016 cost around 33% of Haiti's GDP, pushing many of the country's residents further into poverty.[156]

Since 2001, there have been multiple measures to strengthen the country's ability to anticipate, face and resist natural disasters and to recover from the impacts in their aftermath. Haiti's economy heavily relies on primary sectors (agriculture, forestry and fishing), which are highly vulnerable to the impacts of climatic events.[157] With the frequency and scale of these events expected to increase with climate change, successful measures to reduce the risks of natural disasters become even more important. Understanding the effectiveness of measures and the lessons that can be learned from them is crucial.

Disaster risk reduction (DRR) involves a systemic approach to management in order to limit the loss and damage from natural disasters. It aims to avoid, mitigate, or transfer the adverse effects of risks through prevention, preparedness and response activities.[158] It is a combination of political and administrative policies and activities, involving various actors and technologies as elaborated below.[159]

Text Box 1: Factors influencing vulnerability to natural disasters

Vulnerability to natural disasters is complex. It is determined not only by the geographical (and meteorological) situation. It also involves social, anthropological, economic, environmental, technical and engineering factors that influence a group's ability to anticipate, face and resist a natural disaster and to

[151] Joseph (2010). Recurrence des catastrophes en Haïti: reflexion sur leurs causes et sur la gestion des risques de catastrophe. University of Geneva, Switzerland.
[152] Reliefweb, 2021, Haiti approves a new Risk and Disaster Management Plan, https://reliefweb.int/report/haiti/haiti-approves-new-risk-and-disaster-management-plan
[153] International Federation of Red Cross and Red Crescent Societies (IFRC) (2015). How law and regulation support disaster risk reduction: Haiti case-study report. Available at https://disasterlaw.ifrc.org/sites/default/files/media/disaster_law/2020-09/HAITI%20DRR%20Report.pdf
[154] International Federation of Red Cross and Red Crescent Societies (IFRC) (2015).
[155] International Federation of Red Cross and Red Crescent Societies (IFRC) (2015).
[156] Green Climate Fund (2019) Readiness and Preparatory Support Proposal for Republic of Haiti. Adaptation planning. Available at https://www.greenclimate.fund/document/adaptation-planning-support-haiti-through-undp
[157] Green Climate Fund (2019).
[158] Joseph (2010)
[159] Lettieri et al (2009). « Disaster management: findings from a systemic view » in Disaster Prevention and Management, Vol. 18, No. 2, Emerald Group Publishing Limited.

recover from its impacts. Risk exposure to natural disasters is hence a combination of vulnerability factors, including the (in)ability to adapt, and the characteristics of the natural disaster itself (cyclones, flooding, earthquakes, etc.), and the chance of occurrence.[160]
There are different factors that increase vulnerability to natural disasters.[161]

- Deep causes affect the allocation and distribution of resources among population groups. This includes economic, demographic and political processes, as well as legal institutions.
- Dynamic pressures: these are processes that transform the deep causes into conditions that are temporally and spatially dangerous. These include the lack of local institutions, capabilities, investments, local markets, press freedom, ethical standards.
- Dangerous conditions: these regard the specific forms in which the vulnerability of a population is manifested. These include for instance placements in dangerous zones, lack of building codes, lack of financing for more resistant housing, among others.

From an NSI perspective, there are several structural elements that can influence the vulnerability of a population. Weak institutions may not provide strong enough regulations for building codes and settlements, or clear guidance for acting when facing a disaster. Lower actor capabilities regarding access to finance and knowledge may affect their ability to prepare for a disaster, for instance to build safer homes and to know how to react in different situations. The ability to cope during a natural disaster, for instance to organize rescue activities and humanitarian support, requires communication between actors. Here, weak networks between actors are expected to pose a challenge. Lack of reliable and disaster-resistant infrastructure, such as telecommunication networks and roads also influence the ability of a population to prepare and respond to a disaster. Strengthening functions of an NIS can help a country overcome important systemic issues related to disaster risk reduction, for instance by increasing knowledge development and sharing about risk exposure and management of natural disasters, mobilizing finance for resilient infrastructure, and creation of legitimacy by establishing guidelines and protocols.

3.3.2 Legislative framework

Until 1997, actions related to natural disasters in Haiti dealt mainly with disaster response, with little focus on preparedness.[162] After hurricane Georges in 1998 that begun to change. Prevention and risk management increasingly received more attention, including from international partners providing support in the aftermath of disasters.[163] The Government of Haiti started to prepare the first national plan for disaster risk management, called “Plan National de Gestion des Risques et des Désastres (PNGDR)”.[164] The PNGDR was ready in 2001, raising disaster risk management to the highest priority.[165]

The PNGDR has two main objectives:

- To address the factors that increase vulnerabilities and risk in order to reduce the possibility of a disaster occurring.[166] At the time, there was an understanding that managing the country’s vulnerability and risk to natural disasters was a fundamental requirement to achieve sustainable development and fight poverty.[167]
- To strengthen the capabilities of actors at all levels – central, departmental, communal and local – to respond to needs in the event of a disaster. [168]

The PNGRD established the National System for Disaster Risk Management (Système National de Gestion des Risques et des Désastres - SNGRD) as the main coordination mechanism for disaster risk management. The SNGRD includes actors related to all different aspects of the prevention and mitigation of, and response to, disasters, ranging from the public sector to civil society, including the private sector, NGOs, international donors

[160] Wisner et al (2004). «At risk, second edition: Natural hazards, people’s vulnerability and disasters ». Routledge, London and New York.
[161] Wisner et al (2004).
[162] Joseph (2010).
[163] Joseph (2010).
[164] Republique d’Haiti (2001). Plan National de Gestion des Risques et des désastres. Available at https://www.preventionweb.net/files/29734_plannationaldegestionrisquesetdesas.pdf
[165] République de Haiti (2019). Plan national de gestion des risques de désastre 2019 – 2030. https://www.preventionweb.net/files/72907_plannationaldegestiondesrisquesdeds.pdf
[166] Joseph (2010)
[167] République de Haiti (2019).
[168] Joseph (2010)

and other actors. This created a network with multiple levels of governance to allow for the management of disaster risks in a more decentralized way.[169] In 2004, the Government of Haiti, with support from the UNDP, used the PNGDR to prepare a national report on the prevention of natural disasters in the context of the 2005 World Conference on Disaster Reduction.[170] Later, the impacts of the 2010 earthquake conferred disaster-risk reduction and disaster-risk management much greater national prominence.[171]

The National Risk and Disaster Management Plan 2019-2030 was adopted in 2021. Four key frameworks were used in its elaboration.[172]

- The strategic development plan of Haiti (PSDH);
- Sectoral policies and plans;
- The regional strategy for global disaster risk management under the Caribbean Disaster Emergency Management Agency (CDEMA); and
- The Sendai Framework for Disaster Risk Reduction.[173]

3.3.3 The Haiti NSI: Actors, institutions, drivers and gaps

A low HDI often correlates to a weak NSI, increasing vulnerability to risks of natural disasters due to difficulties in terms of availability of financial resources, poor housing conditions, and access to education and health.[174,175] In 2000, Haiti had a Human Development Index (HDI) of 0.442, with mean years of schooling of only 3.8 years. In 2019, the country's HDI had improved to 0.510, but Haiti still ranks 170th out of 189 countries, being included in the "low human development category" according to UNDP.[176] A weak educational system, together with a lack of learning from previous events, led to insufficient knowledge among the Haitian population about the risks being faced. Lack of access to finance, as well as insufficient knowledge (e.g. about building codes) among the general population, meant that people could not sufficiently implement measures to limit the damage (e.g. families could not build more resilient homes).[177,178]

There are also factors that affect the ability of public institutions to prepare for and manage risks associated with natural disasters. The country has experienced political instability, including a conflict in 2004 which led to the deployment of a UN Peace Mission in the country. Moreover, a historical centralization of the administration and services around the capital Port-au-Prince has led to people living in vulnerable conditions in urban slums, while undermining the public administration's ability to provide support and services to the rural population in the country's interior.[179]

Several non-state actors engaging in disaster risk reduction and relief activities are operating in the country (UN agencies, bilateral agencies, NGOs), often increasing their presence in the aftermath of a natural disaster. This increases the need for effective coordination. Coordinating support during and after a disaster becomes challenging in the absence of established harmonization tools, such as protocols for rescue and relief operations and clear communication structures. It increases the risk of duplication of actions, leading to an inefficient

[169] Joseph (2010).
[170] Joseph (2010)
[171] International Federation of Red Cross and Red Crescent Societies (IFRC) (2015).
[172] Reliefweb, 2021
[173] The Sendai Framework for Disaster Risk Reduction 2015-2030 was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan in 2015, aiming to 'achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the next 15 years.' It outlines four priorities "to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience and; (iv) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction." Source: UNDRRR, 2005, Sendai Framework for Disaster Risk Reduction 2015-2030, https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
[174] Joseph (2010)
[175] World Bank's Climate Risk and Adaptation Country Profile (2011)
[176] UNDP (2020) The Next Frontier: Human Development and the Anthropocene. Briefing note for countries on the 2020 Human Development Report. Haiti. http://hdr.undp.org/sites/default/files/Country-Profiles/HTI.pdf
[177] Joseph (2010)
[178] Schacher (2014) Disaster-Risk Reduction through the Training of Masons and Public Information Campaigns: Experience of SDC's "Competence Centre for Reconstruction" in Haiti. In John F. Shroder, Max Wyss, Hazards and Disasters Series, Earthquake Hazard, Risk and Disasters https://doi.org/10.1016/B978-0-12-394848-9.00003-1
[179] Joseph (2010)

allocation of scarce resources, and can lead to transaction costs for actors, e.g. because of duplicate reporting needs.[180]

Infrastructural issues increasing the country's vulnerability include the fact that all main cities and electrical cables and gas/fuel storage facilities are built on the coast, which are at risk of flooding, exposing residents to both direct flood risks as well as the safety risks of flooded wiring.[181] In addition, structural engineers are mostly involved in the design of high-rise buildings, being more financially attractive. This leaves the design and construction of low-rise buildings to small-scale contractors, who do not always have the technical knowledge to build more resilient infrastructure.[182] High deforestation rates, including for biomass for cooking also increases risk exposure to certain natural disasters.

To reduce vulnerability and increase the country's ability to anticipate, face and resist natural disasters and to recover from their impact several of these gaps were covered by the PNGRD objectives:

- Institutional actions needed to be strengthened around a long-term vision for disaster risk reduction, in coordination between the Haitian government, other national actors, and international donors.
- A mechanism for valuing local participation and knowledge was required, based on the experience from the 2010 earthquake that local networks of neighbors were crucial for rescue operations.
- The creation of a system for knowledge development and knowledge sharing was another key point to increase awareness and capabilities to prevent and manage future disasters.
- A revision of the school curriculum was needed, in order to adapt knowledge production and learning to the local needs in relation to natural disasters.
- Standards and protocols had to be developed regarding all phases of risk management and response to natural disaster to facilitate action in the face of an event, as well as monitoring and evaluation processes.[183]

The Directorate for Civil Protection (DPC) of the Ministry of the Interior and Territorial Communities (MICT) is primarily in charge of risk and disaster management in Haiti. In 2019, a law was in discussion to provide more capacity and autonomy.[184] With the approval of the DRM Law in June 2020, DPC has become a General Directorate (GDPC) within the MICT.[185] The law of 5 June 2020 formalized the PNGRD and designated DGPC as "an autonomous body responsible for technical coordination, knowledge management, technical support and strengthening the capacity and mobilization of the SNGRD".[186]

3.3.4 Description of the initiatives

The main aspects of the government's top-down approach as laid down in the PNGRD will be described below. However, several initiatives have been implemented by non-state actors like NGOs and international donors. While a review of all initiatives goes beyond the scope of this case study, two examples of such bottom-up interventions are also discussed below.

3.3.4.1 Government-led initiatives under the PNGRD framework

Creation of a network of local committees for disaster risk management: committees for disaster risk management were established at the local level, making sure that every town had its own committee, reducing dependence on centralized governance structures from Port-au-Prince. Moreover, this network created a

[180] De Silva and Prustalis (2010). The Sahana Free and Open-Source Disaster Management System in Haiti. In: ICT for Disaster Risk Reduction. Chapter 2. Incheon City, Republic of Korea: United Nations APCICT-ESCAP
[181] Joseph (2010)
[182] Schacher (2014)
[183] Joseph (2010)
[184] UNDRR, 2019, Haiti works together with the United Nations Office for Disaster Risk Reduction - Regional Office for the Americas and the Caribbean to strengthen its presence and commitments into Caribbean risk reduction initiatives, https://www.eird.org/americas/news/haiti-works-together-with-the-united-nations-office-for-disaster-risk-reduction.html#.Ys2aEHZByUkUn
[185] World Bank GFDRR, 2021, Building Physical, Fiscal and Inclusive Resilience in Haiti, https://www.gfdrr.org/en/building-physical-fiscal-and-inclusive-resilience-haiti
[186] Republic of Haiti, Ministry of Planning and External Cooperation, 2021, Post-Disaster Needs Assessment in Haiti: Earthquake of 14 August 2021 in the Southern Peninsula; Executive Summary, see: https://www.ilo.org/wcmsp5/groups/public/---ed_emp/documents/publication/wcms_831127.pdf

common core curriculum for training in disaster risk preparedness and responses, conducted education and awareness raising activities among the population, and improved coordination. It also helped to create an emergency plan that established a mechanism for organizing interventions in the case of an event, including a coordination unit composed of at least three people, and guidelines for communication management in emergency settings.[187]

Implementation of platforms and mechanisms for institutional and intersectoral coordination, both at strategic and operational levels: the establishment of platforms such as the SNGRD, the International Cooperation Support Group (GACI), the NGO Forum, thematic committees on DRR aspects, as well as the UNDP Civil Society Advisory Committee, have helped to promote the development, systematization and standardization of tools and practices, such as plans, protocols and procedures. The establishment of Emergency Operations Centers (EOC) by the Directorate of Civil Protection (DPC) of the Ministry of the Interior, created a framework to provide coordination during emergency situations.[188] EOCs allow local emergency response personnel to collect and analyze reported information, make decisions, and manage Haiti's collective response to natural disasters.[189] Various EOCs were established over the years in different locations, and in 2021 a national EOC (COUN) was established. The EOCs publish regular reports.[190]

Figure 9 Communication during emergencies[191]

Development of plans, protocols, procedures, and other management tools: as established by the PNGRD from 2001, several guidelines were developed, including:

- A disaster response plan (2001, updated in 2009);
- A manual for the organization and operation of the EOCs (2006, revised in 2017); and
- A guide for management of evacuation shelters (2013).

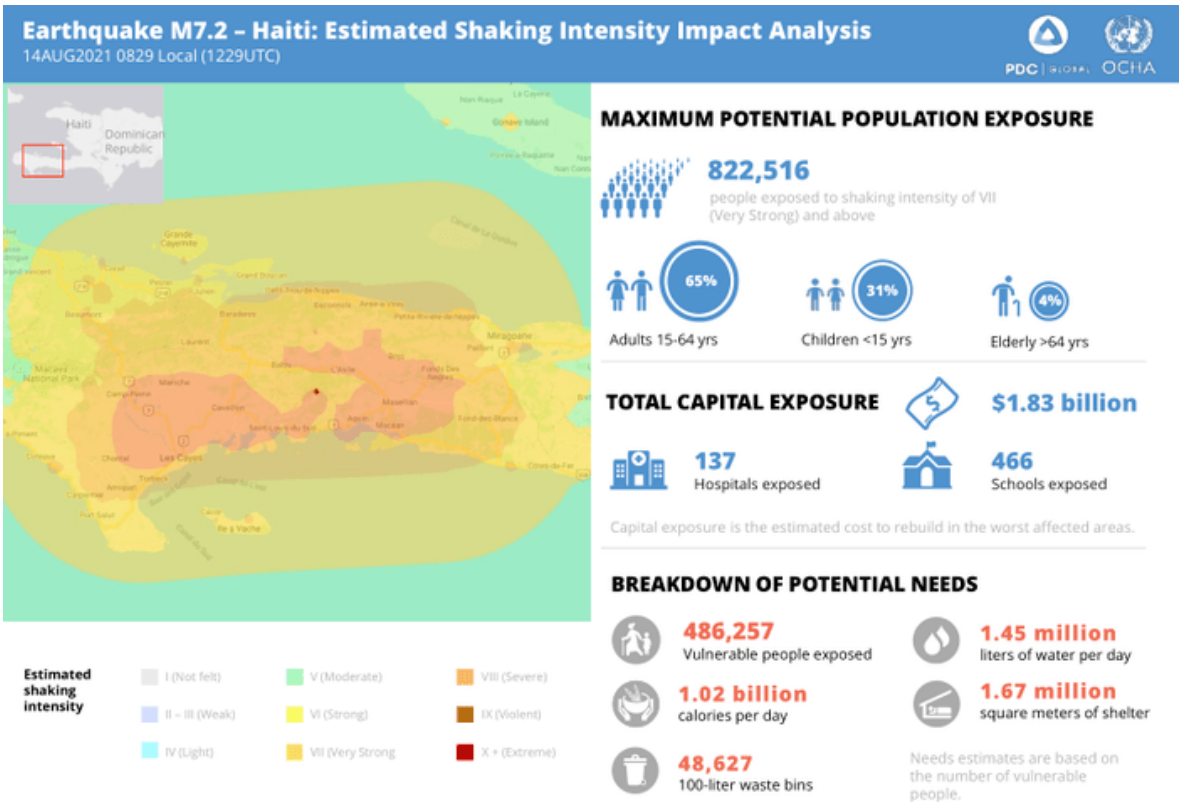
In addition, several action and contingency plans were developed and revised annually.[192]

[187] République de Haiti (2019).
[188] République de Haiti (2019).
[189] Reliefweb, 2012, Ground-breaking Ceremony for Disaster Response Facilities in Miragoane, https://reliefweb.int/report/haiti/ground-breaking-ceremony-disaster-response-facilities-miragoane#:~:text=The%20Emergency%20Operations%20Center%20will,provide%20relief%20to%20affected%20populations.
[190] Reliefweb, 2021, Haiti Earthquake ETC Situation Report #2 Reporting period 20/08/2021 to 26/08/2021, https://reliefweb.int/report/haiti/haiti-earthquake-etc-situation-report-2-reporting-period-20082021-26082021
[191] https://www.worldbank.org/en/results/2021/10/12/strengthening-disaster-risk-management-and-transport-infrastructure-after-a-disaster-the-2010-haiti-post-earthquake-expe
[192] Such as plans for hydrometeorological and seismic contingencies and procedures for meteorological monitoring developed by the Hydrometeorological Unit of Haiti (UHM). Source: République de Haïti (2019) République de Haiti (2019).

Information management: improving information management was a priority in the PNGRD both during an emergency and in normal times. Haiti put in place mechanisms for the collection of data on disaster risks, vulnerabilities and impacts, including the creation of a national database. The country also established information management cells and trained and hired personnel for handling and analyzing the data, both in the field and in the EOCs.[193] DPC established a national early warning system (EWS) under the PNGRD and procedures for risk mapping, also with the support from international partners to implement effective EWS in many communities.[194]

Training and communication activities: the PNGRD 2001 led to the creation of several new courses covering the fundamental principles in DRR such as the understanding of risks of, preparedness for and potential responses to natural disasters. This included trainings and information sharing (amongst others about alert systems, rapid assessment of damage and needs, management of evacuation shelters, management of emergency operation centers, simulation exercises). There were also initiatives to increase awareness on DRR issues within formal educational programmes, including at university level via, for instance, the creation of a post-graduate programme. Some of these initiatives were established in collaboration with foreign universities such as the Swiss University of Geneva and the French University of Nice.[195]

Figure 10 Example of communication material on the impacts of earthquakes[196]



Moreover, the Thematic Committee for Education and Public Awareness (CTESP) was created to provide coordination in awareness raising activities. This committee brings together the main DRR stakeholders in support to DPC, aiming to improve public knowledge regarding main disaster risks and the best practices to reduce these risks to implement throughout all phases of a disaster. The Committee's activities aimed to increase not only the awareness about the possibility of, and risks associated with, natural disasters, but also to enable actors to act in the face of events and to anticipate and recover from impacts of such events. The targeted audience comprized individuals, families and local communities, including local leaders and the media. CTESP

[193] République de Haiti (2019).
[194] IFRC (2015)
[195] République de Haiti (2019).
[196] Reliefweb, 2021, Earthquake M7.2 – Haiti: Estimated Shaking Intensity Impact Analysis, see: https://reliefweb.int/report/haiti/earthquake-m72-haiti-estimated-shaking-intensity-impact-analysis

also carried out the validation, harmonization and systematization of hundreds of audiovisual tools and general activities for education an awareness raising. [197]

Regarding communication activities, the government carried out multiple efforts to inform the population, especially the most exposed and vulnerable groups, about disaster risk reduction and management, both on how to prevent disaster risk, and how to respond to a disaster as it happens. These efforts included communication campaigns by local volunteers and DPC, as well as the use of media campaigns, in newspapers, on television, but also using mobile communication and social media. These activities were carried out during emergencies and in normal times.[198]

Integration of DRR into strategic documents: disaster risk management and reduction were integrated as a cross-cutting issue into government planning, being directly associated with general environmental, poverty reduction and social development policies. Moreover, the Ministry for Planning and External Cooperation (MPCE) has carried out efforts to include DRR as a conditionality for all international cooperation programmes and projects, in as similar way to what is currently done for the requirement to include environmental impact assessment studies.[199]

Establishment of public financial instruments: A law from 16 September 1966 had created a public fund for emergency situations, by collecting 1% of salaries, initially from public employees, but later also from the private sector.[200] In addition, the government established dedicated budget lines for emergency response and preparedness. Haiti had multiple risk-financing instruments in place, supported by the World Bank and partners such as the European Union, benefitting from funding innovations in disaster-risk financing.
Haiti has subscribed to the Caribbean Catastrophe Risk Insurance Facility (CCRIF), a regional insurance mechanism which makes insurance funds available rapidly after a natural disaster strikes.[201] The CCRIF provided US$ 7.7 billion to Haiti after the 2010 earthquake, accounting for around half of all funding the country received in the first 10 weeks after the event.[202] The subscription to CCRIF SPC[203] reflects shift the focus from reactive post-disaster response to a more proactive approach focusing on prevention and preparedness.
Haiti has other mechanisms in place, such as the World Bank's Contingency Emergency Response Component (CERC), which allows funds to be reallocated from existing projects to address emergency response needs. The Bank is also working with the Government of Haiti and other development partners on a comprehensive needs-assessment and recovery plan. This will be used to mobilize funding from the World Bank and partners for a resilient and inclusive recovery and reconstruction in Haiti.[204]

3.3.4.2 Civil society led initiatives after the 2010 earthquake

Following the 2010 earthquake some bottom-up initiatives to improve DRR in Haiti were led by NGOs, volunteers and international donors. Two relatively well-documented examples are given below.
Knowledge for resilient reconstruction: After the 2010 earthquake, the Swedish Agency for Development and Cooperation carried (SADC) out a project to re-build a school and offer training for the local population at the periphery of the earthquake-affected area. SADC explicitly focused on the rural areas of Haiti, where the involvement of structural engineers in construction projects is rather low, leading to less-resilient buildings. The aim was to increase infrastructure resilience during the reconstruction phase and augment local capacities. They provided support in developing and disseminating appropriate building techniques and improving general public awareness of earthquake and hurricane-resistant building methods. [205]

[197] République de Haiti (2019).
[198] République de Haiti (2019).
[199] République de Haiti (2019).
[200] It is as yet unclear whether this fund still exists.
[201] CCRIF SPC was established in 2007 as the first multi-country risk pool in the world with technical support from Japan. CCRIF SPC is capitalized by premiums paid by its member countries and funds from various donors, such as Canada, the EU, Germany, Ireland, and Mexico, allowing it to sustainably provide disaster-risk financing in the form of insurance to Central American and Caribbean countries.
[202] République de Haiti (2019). pdf
[203] Segregated Portfolio Company
[204]World Bank, 2021, Haiti's Path to Building Financial Resilience Against Disasters, https://blogs.worldbank.org/sustainablecities/haitis-path-building-financial-resilience-against-disasters
[205] Schacher (2014)

Sahana software for information management during emergency situations: an important challenge during emergency situations regards data collection and management during the response phase to help actors identify the scale of the disaster and coordinate action. This can be especially difficult since infrastructure, such as telecommunication and electricity, is often damaged in the aftermath of a disaster, and remote areas can be more difficult to reach. Additionally, often only limited bandwidth is available, as well as few hardware devices that can run applications. Human resources can be unfamiliar with software, with little time available for learning. In addition, with several organizations and volunteers coming in to help, coordination is crucial to avoid duplication and ensure scarce resources are allocated optimally. If the software used during disaster responses does not address these concerns, actors often go back to manual/offline sources, undermining information sharing and management during the response.[206]

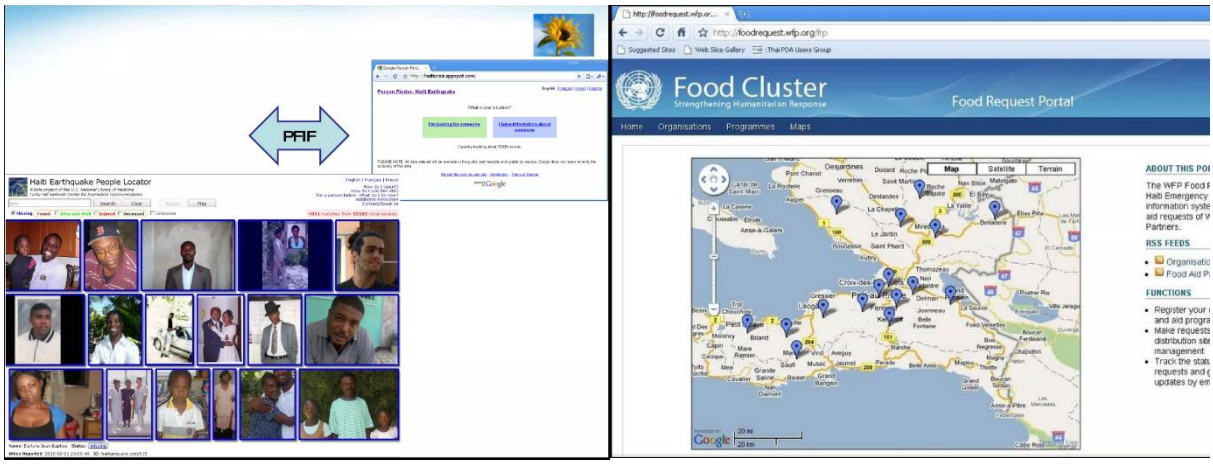
The Sahana Free and Open-Source Disaster Management System was developed by volunteers from the ICT industry to help overcome the challenges created by large scale disasters. It was first deployed in Sri Lanka during the Indian Ocean Tsunami in 2004, but has since been deployed in other countries in the aftermath of natural disasters. It is designed to have the ability to adapt to the constrained environment ICT solutions face during disaster response. For instance, it facilitates the interoperability with existing systems, is bandwidth-efficient, has a quickly accessible interface and can run on low hardware specifications.[207]

Following the 2010 earthquake in Haiti, the Sahana Software Foundation and the Sahana community of volunteers responded with a big voluntary effort. They set up the Sahana Haiti 2010 Earthquake Disaster Response Portal, a live and active public website to help fill gaps in information management during the relief operations.[208] One of the ICT solutions under Sahana known as Sahana's Organization Registry (SOR) provided a searchable database that helped track organizations and offices working on the ground in Haiti on disaster relief, there location, who they were already helping and what assets and resources they had available. SOR became the main repository for contact details during the first weeks of the response. Organizations could self-register by email or report to their office locations.[209] Crowdsourcing of volunteers played an important role in mobilizing human capital for data collection and management, especially since the government capabilities were seriously hampered after the disaster. Volunteers were assigned to assist with data entry into the SOR and to merge information from multiple existing sources.[210,211,212]

The Sahana Software Foundation worked with the U.S. State Department and other actors on a project to process SMS text messages sent from Haitian citizens with requests for assistance. Messages were processed and put into a structured data format providing the sender's name, location and category of the message.[213] The software was also able to gather information from Twitter about affected or missing persons, as well as population needs, using a hashtag system. Sahana centralized the information in a way that all actors could see all requests, as well as which request had already been answered by whom. The repository system was later adapted to synchronize with the Hospital Management System for requests for assistance, resources, staff and medical supplies. It also supported the World Food Programme with identifying needs and planning the distribution of food supply.[214]

[206] De Silva and Prustalis (2010).
[207] De Silva and Prustalis (2010).
[208] De Silva and Prustalis (2010).
[209] De Silva and Prustalis (2010).
[210] De Silva and Prustalis (2010).
[211] Depelteau (2013). L'usage et l'appropriation des communications mobiles textuelles par les acteurs de la réponse humanitaire du séisme du 12 janvier, 2010 en Haïti. Montreal, Canada: Université du Québec
[212] Kankanamge et al (2019) Can volunteer crowdsourcing reduce disaster risk? A systematic review of the literature. International Journal of Disaster Risk Reduction 35 (2019) 101097.
https://doi.org/10.1016/j.ijdrr.2019.101097
[213] e.g., an immediate lifesaving request, missing person report, etc.
[214] De Silva and Prustalis (2010).

Figure 11 Sahana software for Haiti DRR: Left – the People finder; Right – the Food request portal[215]



3.3.5 Assessment of the initiatives

Knowledge development and diffusion: There were several activities in Haiti that contributed to improve DRR knowledge development and diffusion. This includes top-down activities, such as the national database established to provide data on disaster risks, vulnerabilities and impacts, the creation of information management cells and training of personnel for handling and analyzing data under the PNGRD. Bottom-up, the response from the Sahana community via the establishment of the Sahana's Organization Registry also provided a searchable database to help coordinate action in relief operations, with volunteers playing a crucial role in collecting data and uploading it in the database.[216,217,218]

As a result, Haiti now has an openly accessible national database[219] that provides GIS and cartographic data about risks and hazards of river and coaster floods, water scarcity, cyclones, earthquakes and landslide.[220] Information comes from several organizations, including research institutes, government and development partners[221] and has been used by a wide range of actors involve in risk and disaster management, urban planning, agriculture and food security, environmental management, etc.[222] There is room for further improvement, according to the Green Climate Fund, through better integration of climate change-related risks and including data concerning the resilience of different population groups.[223] In addition to the database, Haiti has consolidated EWSs for flooding and hurricanes.[224]

Knowledge diffusion was also aided by educational and training activities under the PNGDR. The establishment of new university courses contributed to the integration of DRR into university curricula, and hence to increasing the overall technical capacities of graduates to handle disaster risk reduction issues in their professional life.[225] The International Federation of Red Cross and Red Crescent Societies (IFRC) observed in 2015 that some good practices can be identified in Haiti's educational policy, such as the fact that environmental education is a mandatory part of the curriculum offers the opportunity to incorporate DRR into the primary and secondary school activities.[226] However, it concluded that the actual inclusion of DRR in the national school curriculum –

[215] Boon, F., 2010, Sahana Foundation's response to Haiti's earthquake, Sahana camp presentation, 7 July 2010, see: https://www.slideshare.net/AidIQ/sahana-reponse-to-haiti-earthquake?from_action=save
[216] Kankanamge et al (2019)
[217] De Silva and Prustalis (2010).
[218] Depelteau (2013).
[219] https://haitidata.org/
[220] https://haitidata.org/
[221] Green Climate Fund (2019).
[222] https://haitidata.org/
[223] Such as information about gender, socio-environmental vulnerabilities and capacities (Green Climate Fund, 2019).
[224] IFRC (2015).
[225] République de Haïti (2019).
[226] IFRC (2015).

beyond universities - still had room for improvement. Bottom-up, NGOs have also been conducting activities to bring awareness of DRR into schools.[227] The project from SADC helped to spread technical knowledge of building codes among the rural population of Haiti, increasing their capabilities to build more resilient homes.[228]

IFRC considered that the structure developed for knowledge development and sharing in Haiti has been relatively effective, with MICT and DPC being able to coordinate a large number of actors at the national level[229]. CTESP contributed to public awareness activities, targeting all types of audiences, and using several communication channels, including the DPC local structures and the mass media[230]. These types of communication activities helped to overcome knowledge gaps among the population, for instance about how to proceed in the face of a disaster or how to be better prepared. IFRC concluded that the network of public awareness information has been generally effective and widespread, with "clearly a large amount of DRR and DRR-related training taking place", led by the DPC and other partners.[231]

All these activities and actors contributed to strengthening knowledge development and knowledge sharing in DRR and DRR-related issues in Haiti. In 2019, the Government of Haiti stated that these measures led to significant progress in terms of coordination, public information and awareness, capacity building for intervention, and the development and diffusion of methods and technologies for the prevention, reduction of risks and response to natural disasters.[232] A report from the Green Climate Fund[233] states that the PNGRD and the SNGRD have strengthened national and decentralized institutions and civil society capacities to address disaster risk management. IFRC also concluded that these initiatives have led to the development of a relatively effective structure at all levels of government that supports coordination across several actors, from public stakeholders, to international donors, to the private sector.[234] In fact, IFRC highlights that Haiti's current annual preparations for the hurricane season are widely praised by those involved in the system.[235]

Entrepreneurial experimentation: The use of the Sahana Open-Source Software can be seen as a bottom-up entrepreneurial endeavor from the Sahana community and users such as volunteers and international donors. The experience with the Sahana software then contributed to other databases being created.

Influence on the direction of the search: Coordination among different actors helped to establish guidance and protocols on DRR and has influenced plans and protocols for DRR since then. For instance, the PNGRD 2019-2030, Haiti's most recent DRR policy plan, builds on past efforts under the 2001 PNGRD while sectoral laws now include DRR-related provisions. This way, the PNGRD helped to create "norms" regarding several DRR aspects in Haiti, for instance on how to communicate about the risks of a disaster, how to react in face of it, how to construct buildings, and so on. This was facilitated via the creation of networks including different types of actors (i.e., from ministries, to communities, local leaders, donors and international volunteers) at all levels: local, sectoral, national and transnational.

Resource mobilization: DRR and relief efforts in Haiti use support from multilateral and bilateral aid agencies, such as the World Food Programme, UNDP, the Green Climate Fund, SDAC and others.[236,237,238,239] The response to disasters in Haiti has also mobilized direct contributions from civil society, for instance via crowdsourcing,[240] the provision of open-source software such as Sahana,[241] as well as support from NGOs.
In 2015, IFRC concluded that Haiti remained chronically under-funded and over-dependent on external funding,

[227] IFRC (2015).
[228] Schacher (2014)
[229] IFRC (2015).
[230] République de Haiti (2019).
[231] IFRC (2015).
[232] République de Haiti (2019)
[233] Green Climate Fund (2019)
[234] International Federation of Red Cross and Red Crescent Societies (IFRC) (2015).
[235] International Federation of Red Cross and Red Crescent Societies (IFRC) (2015).
[236] Green Climate Fund (2019)
[237] Schacher (2014).
[238] De Silva and Prustalis (2010).
[239] IFRC (2015)
[240] Depelteau (2013).
[241] De Silva and Prustalis (2010).

with more than 50% of the government budget coming from international aid. They argued that this impacted the effectiveness of the national system for disaster risk management and that, for instance, DPC would not have been able to maintain its operations without international funding, notably from UNDP.[242] With the establishment of the National Bureau for Environmental Assessments in 2015, some private actors started carrying out environmental impact assessments, but climate-change and DRR-specific investments from the private sector still remained low in 2019.[243] Haiti has been receiving support from the Green Climate Fund to address this issue.[244] Establishing more independent and stable sources of finance remains a challenge to be addressed in order to ensure the long-term effectiveness of the Haiti's national DRR system.

Haiti has, with international support, made efforts to more away from disaster response financing to more strategic – and proactive - strategic disaster-risk financing (DRF), including the subscription to the insurance pool of CCRIF. DRF is important to increase the resilience of countries to natural disasters by establishing more predictable financial resources than international aid can provide. By planning ahead, countries can, for example, invest in shock-responsive safety net mechanisms, registries of beneficiaries, aid logistics, and pre-established national disaster funds, which all facilitate rapid assistance to the at-risk population in a reliable, predictable, and efficient way. Haiti is currently developing a comprehensive DRF strategy, in partnership with the EU's Caribbean Regional Resilience Building Facility, which will likely include instruments such as CCRIF SPC coverage, contingent credit lines, emergency funds, and coordinated budget reallocations.[245]

Legitimation: The PNGDR led to the development of several protocols and procedures for DRR. Importantly, this was done by taking actors and local capabilities into account. A clear example of good practice here is the implementation of the National Building Code, which includes provisions for the design of structures against wind and seismic risks.[246] The code is praised for adapting technical language to make it more understandable for the general Haitian population, at a layman level. Instead of simply setting out very technical requirements and mathematical calculations, it relies on the creative use of diagrams to ensure a larger share of Haitian can understand and apply the code.[247]

The PNGDR also led to the integration of DRR into strategic documents and national planning. Most of Haiti's sectoral laws contain DRR-relevant elements,[248] integrating climate change adaptation concerns into the country's disaster management plan[249] and aligning it with overall development objectives.[250] Nevertheless, in many areas the effectiveness of implementation and enforcement of these laws falls short due to funding and capacity constraints, especially at local levels.[251] DPC is subordinate to MITC, which can lead to a lack of legal certainty according to the IFRC (2015), undermining long-term planning.[252] It is unclear to which extent the new DRM law sufficiently addresses this issue.

Development of positive externalities: In 2019, Haiti's HDI had improved to 0.510 from 0.442 in 2000, in part due improving education and health indicators (with mean years of schooling increasing from 3.8 years to 5.6 years and life expectancy at birth from 57 to 64 years). DRR induced advances can have had a positive impact on such indicators. This can, however, not be substantiated at this point.

In summary, the measures undertaken for DRR in Haiti after 2001 have led to significant progress in strengthening functions of the country's NSI. They have also increased actors' capabilities, created and strengthened networks of actors and established important institutions. These were significant steps to increase Haiti's ability to anticipate, face and resist natural disasters and to recover from their impacts.
Nevertheless, challenges remain to be addressed, especially concerning long-term planning, financial stability and effective implementation and enforcement, due to funding and capacity constraints, especially at the local

[242] IFRC (2015)
[243] Green Climate Fund (2019).
[244] Green Climate Fund (2019).
[245] World Bank, 2021
[246] IFRC (2015)
[247] IFRC (2015)
[248] IFRC (2015)
[249] Green Climate Fund (2019)
[250] République de Haïti (2019)
[251] IFRC (2015)
[252] IFRC (2015)

level. With the development of new international agreements such as the Sendai Framework for Disaster Risk Reduction and the Paris Agreement, a new PNGRD (2019-2030) was adopted. The impact of this is, however, not assessed in this study, due to its recent character. Nevertheless, its development emphasizes the need for continuous monitoring and evaluation to take stock of progress, identify gaps and new developments, and to readapt strategies, in order to ensure effective long-term planning.
Table 8 presents the structure-function coupled analysis of Haiti's DRR activities.

Table 8: Structural-function coupled analysis of the Haitian initiative

Function		Structural element	Interventions
F1	Knowledge development and diffusion	Actors	• Communication campaigns by local volunteers and DPC, as well as the use of media campaigns, in newspapers, television, but also mobile communication and social media • The Thematic Committee for Education and Public Awareness (CTESP) provides coordination in awareness raising activities • Individuals, families and local communities, including local leaders and the media were targeted in awareness raising campaigns • Training for actors involved in data collection and management • Several organizations, including research institutes, government and development partners provide data and information to the national database
		Institutions	• New courses were established at university level • Decentralization efforts, through the empowerment of local committees and initiatives • Creation of sectoral committees for knowledge development and diffusion in certain areas
		Interactions	• Creation of a network of local committees for disaster risk management • Implementation of platforms and mechanisms for institutional/intersectoral coordination, both at strategic and operational levels
		Infrastructure	• Training for building more resilient infrastructure • Creation of national databases • Establishment of early warning systems
F2	Entrepreneurial experi-mentation	Actors	• This function was fostered by several actors, for instance the government, but also local committees, volunteers and international donors
		Institutions	• The use of the Sahana Open-source software helped later with the creation of additional databases, helping to consolidate data management for DRR
		Interactions	• Interactions between networks of the Sahana Community, volunteers, donors and public organizations
		Infrastructure	• Use of Sahana Open-Source Software
F3	Market formation[1]	Actors	
		Institutions	
		Interactions	
		Infrastructure	
F4	Influence on direction of search	Actors	• The government established the SNGRD, a national system for coordination • Multiple actors contributed to improve coordination under several thematic committees
		Institutions	• Established guidance and protocols on DRR have influenced further plans, protocols and even sectoral laws, helping to integrate DRR into national planning
		Interactions	• Strengthened networks promoted interaction between different actors, e.g., between those implementing teaching, and governments and communities • These networks became reference points for the establishment of guidance and protocols for DRR in the country
		Infrastructure	• Plans, guidance, protocols and better information provision about geospatial data have contributed to influence the building of new infrastructure in Haiti, and to integrate more resilience techniques into building practices
F5		Actors	• Government funding

Function		Structural element	Interventions
	Resource mobilization		• International and multilateral financial institutions • International donors such as bilateral and multilateral aid agencies • Volunteers and civil society (e.g., crowdfunding) • Caribbean Catastrophe Risk Insurance Facility (CCRIF)
		Institutions	• Public fund established by the law of 1966 • Dedicated budget lines for emergency response and preparedness. • Participation in regional insurance mechanisms • Preparation of a Disaster Reduction Finance strategy
		Interactions	• Coordination mechanisms via e.g., Sahana database on who is providing support for what, and what the needs are
		Infrastructure	• Mobilization of financial resources and human resources (volunteers) for reconstruction after natural disasters
F6	Legitimation	Actors	• Sectoral committees help with the development of standards and protocols
		Institutions	• Development of plans, protocols, procedures, • Integration of DRR into strategic documents
		Interactions	• Protocols provided guidelines for interaction, clear structure for communication, etc., for preparing and in the face of a natural disaster
		Infrastructure	• Establishment of codes and protocols facilitated the building of more resilient infrastructure
F7	Development of positive externalities[1]	Actors	
		Institutions	
		Interactions	
		Infrastructure	

[1] Please note that grey cells mean that not enough information was available to suggest that the initiatives here discussed have significantly contributed to these functions. This however does not mean that they did not contribute in reality, see e.g. the discussion on potential contribution to the improvement of Haiti's HDI above.

3.3.6 Role of the initiatives in Haiti's NDC

The NDC[253] does not explicit mention the PNGRD as an overarching institutional framework contributing to climate change goals. The updated NDC, however, does mention the need for capability building and technology transfer for Haiti's contribution to climate change mitigation and adaptation, highlighting the importance of this process to be appropriately tailored to the national context and needs.[254] Moreover, it says that in line with its national policy for fighting climate change,[255] the emphasis should be on:

- Building capabilities of actors such as public servants, private sector and civil society on climate change;
- Involving universities in the training and research programmes on climate change-related issues, including the update of the NDC;
- Improving government capacity through reforming legal and institutional frameworks and inter-institutional cooperation;
- Creating an educational, communication and awareness plan for the general public;
- Including climate change and sustainable development in school curricula starting from primary school.[256]

The new PNGRD (2019-2030) does not make a direct link to the country's NDC, but the it was developed in line with Haiti's strategic development plan (PSDH) and sectoral policies and plans. Therefore, given the contribution of past DRR initiatives to strengthening Haiti's NSI in those functions, leveraging the experience, networks and capabilities build for DRR is expected to support the adaptation goals in the NDC.

3.3.7 Key success factors and lessons learned

Haiti's experience with DRR provides some useful lessons learned:

Taking a systemic perspective is important: Vulnerability to natural disasters relates to multiple factors, hence disaster risk reduction requires a systemic approach. In order to have more resilient infrastructure in Haiti, techniques for more resilient buildings had to be developed. For this, new protocols had to be established to harmonize construction practices throughout the country and the university curriculum had to be revisited. Furthermore, for this new knowledge to become widely adopted by the Haitian society, these techniques and codes also had to be shared and communicated with a range of actors. For this, networks had to be strengthened. While the introduction of new technological hardware can support DRR efforts, for instance by providing more resilient construction materials, this will have only limited impact if knowledge – software – and institutions – orgware – are not also developed to support their uptake.

Local knowledge and needs need to be taken on board: In the face of a disaster, local communities are crucial in providing support, since communication and transportation networks are often down. Building the capacity of local communities to prevent and react in the face of a disaster is therefore crucial. Haiti undertook significant efforts to decentralize the administration and empower local communities in DRR. Training and information activities are also more effective when conducted in collaboration with local partners. This ensures that the training and information are better suited to local needs and knowledge, and that they indeed reach the target audience.

Strong networks are crucial in coordination: Strong networks are crucial to provide coordination and ensure effective disaster risk management and reduction. They help sharing and managing information about vulnerabilities of local populations while building capacity of local actors by facilitating access to knowledge. They support the coordination of actions and identification of needs, as well as the establishment of codes of conduct and best practices. Weak networks can significantly undermine a country's ability to anticipate, face and resist natural disasters and to recover from it impacts.

Combined top-down and bottom-up efforts can create synergies: Making use of efforts and infrastructure of bottom-up initiatives such as the Sahana community using the Sahana Open-Source Software to create the SOR increased the scope and effectiveness of Haiti's data management and sharing activities. The bottom-up Sahana activities contributed to other databases being created and increased the amount of data available for inclusion.

[253] République de Haïti (2022). Contribution Déterminée au niveau National de la République d'Haït. https://unfccc.int/sites/default/files/NDC/2022-06/CDN%20Revisee%20Haiti%202022.pdf
[254] République de Haiti (2022)
[255] Politique Nationale de lute contre les Changements Climatiques – PNCC
[256] République de Haïti (2022)

Multi-stakeholder partnerships, including international collaboration, are important: the Haiti case showed the importance of collaborating with a variety of actors, from local to national actors, and including volunteers and international development partners.

Systemic change requires time: Systemic change entails not only changes in technologies, educational programmes and regulatory frameworks, but also a change in behavior. New collaborations need to be formed, knowledge needs to be put into practice, new routines need to be established. Actors need to collaborate with stakeholders they are not used to collaborate with. New practices under building codes need to be implemented in new construction projects. People need to learn new skills and integrate them into their practices. New data collection and reporting practices need to be incorporated into the routine of organizations. Experts conducting trainings need time to identify the needs from the local population and to incorporate feedback into future activities.

Long-term planning and review are important: The case of Haiti highlights a need for continuous monitoring and evaluation to take stock of progress, identify gaps and new developments, and to readapt strategies, in order to ensure effective long-term planning.

3.3.8 Good practices for potential replication

The above lessons learned lead to the identification of the following good practices in the Haiti DRR case that might be replicable in other countries:

- *Focus beyond hardware innovation:* Technological hardware such as satellites can have an important contribution to DRR by helping with early warning systems. However, building capacity of local actors, creating the right communication channels for sharing knowledge and information, and establishing the right regulatory framework are crucial aspects of a DRR strategy.
- *Strengthen local capabilities, while ensuring coordination across different types of actors and levels:* Strengthening capabilities of local communities is crucial for effective DRR action. However, there is also a need for harmonization of curricula, protocols and information management mechanisms. Finding the right balance between bottom-up and top-down processes can be challenging, but can contribute to more effective strategies. Partnerships across a variety of actors can help build capacities and strengthen coordination across levels.
- *Plan according to longer time frames, while allowing monitoring, evaluation and review:* Since systemic change requires time, short-term planning (with too short time frames covering only a couple of years) will only be effective to a limiting degree in achieving objectives. It is therefore important to plan according to longer time frames, while continuously taking account of progress made, and review plans where necessary.

3.4 CASE: BIO-ETHANOL ACTIVITIES IN BRAZIL

Country	Brazil	**Focus**	Mitigation
Scope	Transport, agriculture, energy	**Key innovation system functions**	F1 Knowledge development and diffusion F2 Entrepreneurial experimentation F3 Market formation F5 Resource mobilization F6 Letigimation F7 Development of positive externalities
Approach	Bottom-up and Top-down	**Starting year**	1900s: Early developments from sugarcane sector 1970s: National ethanol strategy 2000s: Market ramp-up, inclusion of sustainability concerns

3.4.1 Introduction of the initiative

The development of sugarcane-based ethanol[257] in Brazil is widely known as one of the most successful cases for rapidly replacing fossil fuels in transport[258]. Flex-Fuel Vehicles (FFVs) using ethanol currently account for over 70% of the Brazilian light vehicle fleet and the country is a leading producer and exporter of the fuel globally[259]. Moreover, the case is often considered unique as it is one of the few cases where a developing country has achieved industry leadership[260]. The Brazilian experience with ethanol fuel can therefore provide useful lessons for other countries.

The Brazilian ethanol innovation system has a long history, shaped by economic and political conditions over time.[261] It can be traced back to Brazil's historical development as a sugar exporter economy. Sugarcane producers looking for income diversification in the early 20th century were the actors to kick-start bottom-up local ethanol experimentation and learning. They also formed coalitions to pressure government for supportive policies. Concerns regarding economic dependency, energy security and the need to promote industrialization were important drivers for government policies that helped to create a market, mobilize funding and establish ethanol fuel regulations.

Consequently, the development of the ethanol TIS in Brazil is the result of a long interaction between bottom-up experimentation initiatives and top-down government policies. Moreover, its trajectory has been shaped by the interaction between a diverse set of actors, institutions and technologies from the agriculture, energy and industry sectors, given the strong links to the sugar, car manufacturing and oil & gas industries[262].

The Brazilian case also shows the importance of adapting technology innovation policies and strategies over time. Different ethanol technologies were developed and supported through the decades, with prioritization changing with available knowledge and evolving societal concerns related to for instance deforestation, GHG emission reduction in transport sector, food security and local governance impacts[263]. Therefore, a distinction needs to be made between different types of ethanol fuel to better understand the dynamics in the innovation system as described in the sections below:

- Hydrous vs. anhydrous ethanol:

[257] Bio-ethanol in Brazil is produced from sugarcane, different from other industry leaders like the United States. When we refer to 'ethanol' in this paper, we refer to bio-ethanol from sugarcane, unless otherwise specified.
[258] Silveira and Johnson (2016). Silveira, Semida; Johnson, Francis X. (2016): Navigating the transition to sustainable bioenergy in Sweden and Brazil: Lessons learned in a European and International context. In Energy Research & Social Science 13, pp. 180–193. DOI: 10.1016/j.erss.2015.12.021.
[259] Campos, Julio N.; Viglio, José E. (2022): Drivers of ethanol fuel development in Brazil: A sociotechnical review. In MRS Energy & Sustainability 9 (1), pp. 35–48. DOI: 10.1557/s43581-021-00016-6.
[260] Andersen (2015). A functions approach to innovation system building in the South: the pre-Proálcool evolution of the sugarcane and biofuel sector in Brazil. Innovation and Development, 5(1), pp. 1–21. DOI: 10.1080/2157930X.2014.996855.
[261] Campos and Viglio (2022)
[262] Andersen (2015)
[263] Stattman, Sarah L.; Hospes, Otto; Mol, Arthur P.J. (2013): Governing biofuels in Brazil: A comparison of ethanol and biodiesel policies. In Energy Policy 61, pp. 22–30. DOI: 10.1016/j.enpol.2013.06.005.

Hydrous ethanol is used for 100% ethanol-fueled engines, while anhydrous ethanol is usually blended with gasoline[264].

- "First generation" vs. "second generation" ethanol:
  First generation ethanol (E1G), like with other biofuels, are usually produced using biomass that could also have been used for food production, for instance sugarcane (in Brazil) and corn (in the United States). Second generation ethanol (E2G) is produced from non-food biomass, for instance perennial grasses or sugarcane residues (called "bagasse"). This type of ethanol is also referred to as "cellulosic ethanol" due to the chemical process involved. E2G is usually considered a more sustainable option due to lower trade-offs with food production[265].

3.4.2 Legislative framework

The ethanol innovation system in Brazil was initially developed as part of a sugarcane/agricultural innovation system, related to efforts from sugar cane producers and the local government to promote economic diversification and reduce dependency on the international sugar market. The first regulatory agency responsible in this area was the Sugar and Alcohol Institute (IAA), established in 1933. The first regulation for ethanol was Decree 1.917/1931 from 1931, stipulating a 5% blend into gasoline, which was followed by several further regulations to increase required blending shares in the following decades. In the 1970s, the government identified ethanol as an industry of national interest and established ProÁlcool, the first national ethanol programme. The National Alcohol Commission (CNAL) was created to implement the programme.

Later, in the 1990s, ethanol regulation progressively moved from the agricultural sector to the energy sector. The IAA and CNAL became defunct at the end of the ProÁlcool programme, with the sector liberalization and deregulation[266]. The National Council of Energy Policy (CNPE) and the National Petroleum Agency (ANP) were created as government bodies responsible for providing guidelines for the energy sector as a whole, including ethanol fuels[267]. One important stipulation from ANP is the "clause of the 1%" from Law 9.478/1997, which requires oil & gas exploration companies exploring in Brazil to invest 1% of their gross revenue from these activities in R&D projects "to the interest of the national energy sector".[268]

Since then, developments in the ethanol sector in Brazil have been driven mainly by energy policy.[269] In 2017, national biofuel policy RenovaBio was established, the first Brazilian ethanol strategy that explicitly incorporated environmental and other sustainability concerns. In 2019, GHG emission targets were established for the fuel mix, to be implemented via a certification scheme (see Section 2.5.4.3). Table 9 below summarizes 25 years of main bio-ethanol related regulations in Brazil.

[264] Campos and Viglio (2022)
[265] Tete, Marcelo and De Souza, Eda Castro (2017) A Formação e o Desenvolvimento do Sistema Tecnológico de Inovação em Etanol de Segunda Geração Brasileiro. ALTEC 2017, XVII Congresso LatinoAmericano de Gestão Tecnológica, 16-18 October 2017.
[266] Like many other countries, Brazil went through liberalization reforms in the 1990s which included measures such as reducing government interventions by promoting deregulation and privatization in the energy sector.
[267] Campos and Viglio (2022)
[268] It was not further defined as what that would exactly entail.
[269] Sousa et al (2016)

Table 9 Main regulations for the Brazilian ethanol sector[270]

Year	Mechanism	Number	Resolution
1997	Law	9.478	Defines the national energy policy; oil monopoly-related activities; institutes CNPE and CNP
1998	Law	9.660	Establishes criteria for the gradual substitution of the official government fleet for biofuel-powered vehicles
1999	CIMA resolution	15	Suspends payment for hydrated ethanol producers
2005	ANP resolution	36	Establishes technical specifications for anhydrous and hydrous ethanol commercialized in the country
2005	Law	11.097	Introduces biodiesel in the Brazilian energy matrix
2006	ANP resolution	5	Requires the registration of suppliers, distributors and importers of ethanol fuel by ANP
2009	ANP resolution	9	Requires fueling stations to label the fuel as "ethanol" instead of "alcohol"
2011	ANP resolution	67	Requires minimum anhydrous ethanol stocks and proof of ability to meet the blend mix
2011	Law	12.490	Includes ethanol among the products to be regulated by ANP (production, distribution and sales)
2014	Law	13.033	Establishes that federal blend mandates can range from 18% and 27.5%
2015	MAPA resolution	75	Mandatory 27% ethanol blend for gasoline
2017	Law	13.576	Institutes Renovabio – the national biofuel policy
2018	Law	9.308	Defines attributions for ANP within the biofuel sector
2018	ANP resolution	758	Regulates biofuel production certification and inspecting firm's accreditation
2019	ANP resolution	802	Regulates decarbonization credit issuance for certified importers and producers
2019	Presidential decree	265	Defines the annual mandatory targets for the reduction of greenhouse gas emissions required for the commercialization of biofuels

3.4.3 The Brazilian NSI: Actors, institutions, drivers and gaps

The Brazilian national innovation system is relatively well developed with interactions between multiple state agencies that promote innovation ensuring a broad mix of policies, ranging from technology-push to demand-pull.[271] Key institutions and actors exist across education and research, production and innovation, as well as public and private funding. Innovation policies, over time but especially in the 21st century, contributed to an NIS that is able to produce frontier knowledge in some key areas, including in the oil & gas and agriculture sectors. For instance, the Brazilian Agricultural Research Corporation (Embrapa), a key player in ethanol innovation, is considered a learning organization of excellence in the agricultural domain. Public funding for innovation enables long-term finance commitments, via organizations such as the Brazilian National Development Bank (BNDES) or innovation funding agency FINEP.[272]

Public initiatives in support of technology parks, including substantial investments from FINEP and the National Council for Scientific and Technological Development (CNPq) and a national incubator policy (PNI), had enabled the establishment of 94 technology parks and over 280 incubators nationally by 2013. Additionally, several sectoral programmes followed a mission-oriented approach in recent years and were considered quite successful, including one from the ethanol sector (PAISS).[273]

Nevertheless, while the variety of actors ensures a richness in policy instruments, it can sometimes also result in fragmentation between scientific research & education and the productive sector, as seen in Brazil. This can

[270] Campos and Viglio (2022)
[271] Mazzucato, M. and Penna, C. (2016) The Brazilian Innovation System: a Mission-oriented Approach. Temas Estratégicos para o Desenvolvimento do Brasil. Março, (1). Centro de Gestão e Estudos Estratégicos (CGEE). Brasília, Brazil. Available at: https://www.cgee.org.br/the-brazilian-innovation-system
[272] Mazzucato and Penna (2016)
[273] Agricultural Joint Action Plan. Mazzucato and Penna (2016)

lead to a lack of direction for innovation, as well as low demand for knowledge produced in academia. This together with a low propensity for private actors to invest in R&D implies that the strongest gap in the innovation system is in fact a coordination issue. That is, the main systemic problem does not refer to an absence of skilled researchers or to a low stock of scientific knowledge, but to a lack of uptake of this knowledge due to a weak coordination between knowledge producers and users[274]. The success of the Brazilian ethanol TIS can be explained by the ability of actors to overcome this systemic problem by ensuring coordination through networks – either in a bottom-up way, e.g., via research and industry associations, or in a top-down manner through the active engagement of stakeholders throughout the innovation and supply chains promoted by government.

3.4.4 Description of the initiatives

Given the interactions described above, we first outline the early development of the bioethanol TIS, initially driven by the sugarcane sector. The following sub-section explains how ethanol subsequently became part of a broader national strategy for energy security and industrialization in the 1970s, with a main milestone being the establishment of the national bioethanol programme Pro-Álcool. Finally, the most recent programmes allowing for the market ramp up of FlexFuel Vehicles and for the introduction of climate change-related concerns in bioethanol policies are explained.

3.4.4.1 Early development: ethanol for economic diversification in the sugar cane sector

Already in the late 19th century, a historical economic dependency on sugar exports in times of crises on the international sugar market led to efforts to develop alternative uses for sugarcane. Public decrees[275] helped mobilize funding for innovation and modernization of the sugar industry. As a result, several sugar mills started experimenting with sugarcane-based biofuels in the 1920s, while pressuring the government to promote the diversification of sugarcane uses. The Estação Experimental de Cana de Piracicaba (EECP) promoted knowledge development and experimentation, and provided coordination between scientists and sugar mill owners. Local equipment suppliers and repair & maintenance shops started manufacturing components that needed frequent replacement and upgraded their own competences. These efforts led to the first introduction of an ethanol fuel variety in the market in 1927, while the work of EECP built a sound base for future innovation activities under e.g., the Agronomic Institute in Campinas (IAC) and the Copersucar Sugarcane Technology Center (CTC) in the 1940s-1970s. [276]

The Great Depression (1929-1939) contributed to reinforce the government interest in developing an ethanol industry. A first compulsory addition of 5% of ethanol (anhydrous alcohol) to imported gasoline was introduced in 1931. In 1933, The Sugar and Alcohol Institute (IAA) was established to regulate the installation and operation of ethanol distilleries, as well as their buy and sell quotas, and provided technical and financial support. The IAA had the responsibility to regulate the national fuel mix together with the National Petroleum Council (CNP)[277]. The ethanol industry officially became an "industry of national interest" in 1942 due to further sugar overproduction during the 2nd World War. Import restrictions during the war created an additional incentive to produce capital goods locally, including the equipment and technologies for ethanol production. Policy incentives followed, resulting in the industry expansion.[278,279]

Various developments in national politics, as well as both national and international markets, resulting in another period of sugar overproduction in the early 1960s, led to further efforts to further develop ethanol production. The Sugarcane Technology Center (CTC, an R&D center) was created by the Brazilian sugarcane private sector, represented mainly by the cooperative Copersucar in 1969. Moreover, several government initiatives were developed, including the National Plan for Improvement of Sugarcane (PLANALSUCAR) in 1971, a long-term R&D programme with five regional operation centres that supported regional experimentation.[280]

[274] Viotti, E. B. (2002). National learning systems: A new approach on technological change in late industrializing economies and evidences from the cases of Brazil and South Korea. *Technol. Forecast. Soc. Change*, **69**(7), 653–680, doi:10.1016/s0040-1625(01)00167-6
[275] 2.687/1875 and 10.393/1889
[276] Andersen (2015)
[277] Campos and Viglio (2022)
[278] Campos and Viglio (2022)
[279] Andersen (2015)
[280] Campos and Viglio (2022)

Figure 12 Sugar cane harvesting

3.4.4.2 Ethanol to promote energy security, economic growth and industrialization ProÁlcool

In 1973, the oil crisis further exposed Brazil's reliance on oil imports and commodity exports. To promote energy security and reduce Brazil's economic vulnerability to external shocks, the government created the National Alcohol Program (ProÁlcool) in 1975. It was part of the "National Development Plan II" and had four main goals:

1) Increase domestic ethanol production to reduce demand for import fuels and energy dependence;
2) Create additional income opportunities for the Brazilian sugar industry;
3) Better leverage Brazilian natural resources for economic development; and
4) Promote the growth of the agricultural and industrial sectors. [281,282,283,284]

To coordinate implementation, the government established the National Alcohol Commission (CNAL).[285]

ProÁlcool stimulated innovation in ethanol from production to distribution and final use.[286] The programme also focused on creating a market for ethanol, to be done in three steps:

- First, promote the mixture of anhydrous ethanol to gasoline;
- Second, adapt gasoline car engines to ethanol use;
- Third, to develop special engines to run exclusively on hydrated ethanol[287].

To implement this, the government established minimum requirements for the share of ethanol to mix with gasoline, ranging from 5-25%. It also provided fiscal incentives and financial loans with subsidized interest rates for sugarcane producers to expand and adapt ethanol processing plants, and for the automobile industry to develop ethanol-fuelled vehicles. Public funding support was substantial, potentially up to 90% of the funding needed for building new ethanol distilleries, and even up to 100% for increasing production of sugarcane. Cumulative subsidies for ProÁlcool are estimated at approximately US$7 billion between 1975 and 1989. In addition, the government determined minimum ethanol sales prices via Petrobras, the national oil and gas company, to make ethanol production more attractive than exporting sugar. Petrobras also provided minimum purchase guarantees to ethanol producers. The government established production quotas to avoid fluctuations

[281] Campos and Viglio (2022)
[282] Francisco (2022). "Proálcool"; Brasil Escola. Available at: https://brasilescola.uol.com.br/brasil/proalcool.htm
[283] Gomes da Cruz et al (2012) A Evolução da Produção de Etanol no Brasil, no Período de 1975 a 2009. Documentos techno-científicos. Vol.43 n.4, pp.141-159
[284] Stattman et al (2013)
[285] Campos and Viglio (2022)
[286] Silveira and Johnson (2016)
[287] Stattman et al (2013)

in supply and price. This would result in consumer prices for ethanol always remaining below gasoline prices (per kilometre driven). [288,289,290]

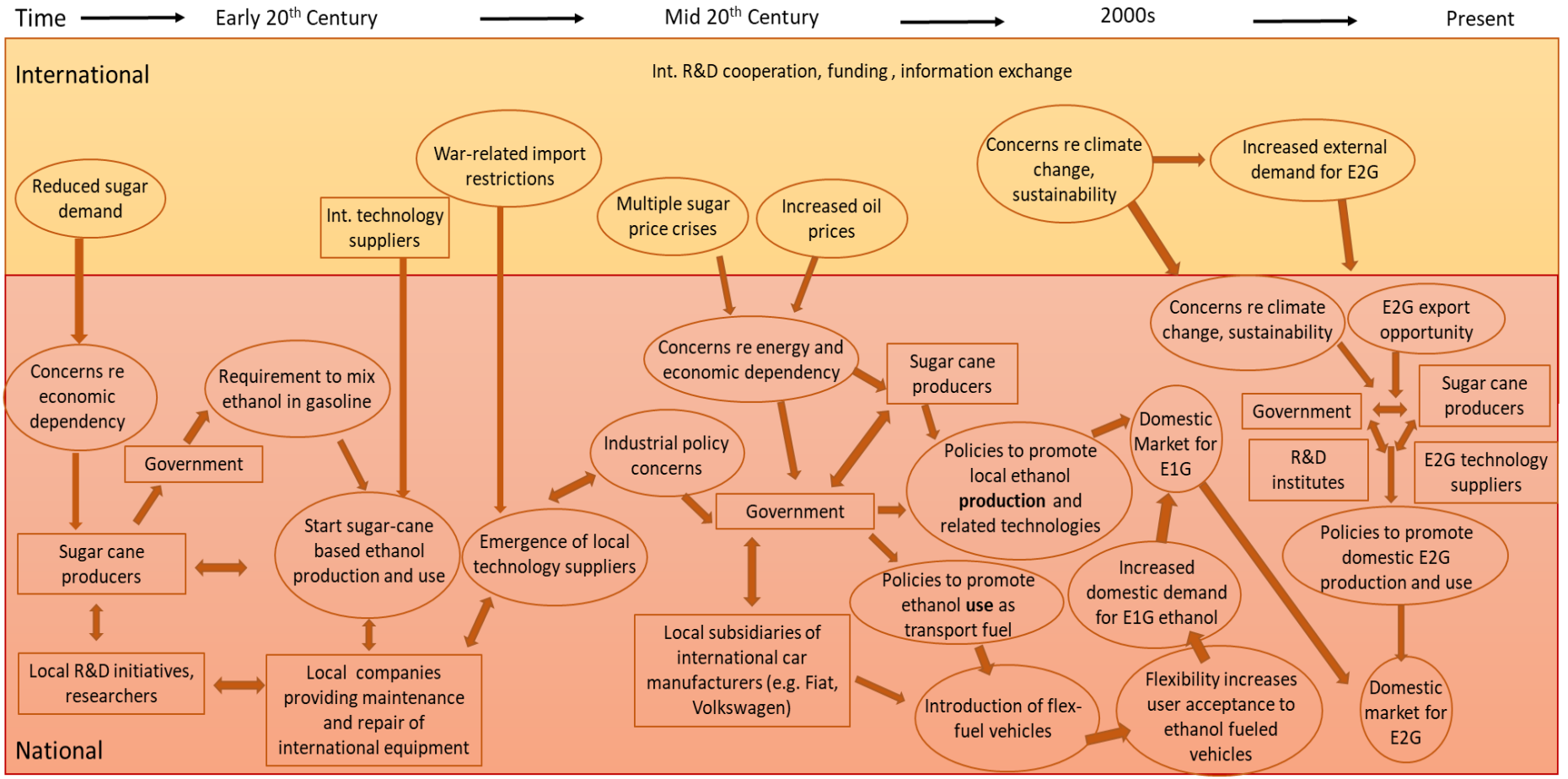
Government played a key role in bringing stakeholders together and overcoming their resistance[291]. Initially, resistance came from all sectors. Sugar mill owners argued that sugar was a less risky market given IAA's price guarantees, despite a similar system created for ethanol. Petrobras expressed concerns about ethanol as possible competition for gasoline. The automobile industry was not in favour of adapting car engines for ethanol solely for the Brazilian market. Government efforts to overcome such concerns led to an increase in ethanol production, employment generation and income creation in rural areas. It also led to the introduction of the first ethanol vehicles in Brazil in 1978. [292,293]

In 1979, the 2nd oil crisis consolidated ethanol as an alternative energy supply source in Brazil. The following years focused on increasing efficiency and developing ethanol supply infrastructure, as well as creating a market for ethanol by supporting the deployment of ethanol-fuelled vehicles and stimulating ethanol use in the chemical sector.[294,295]

Measures to stimulate the market for ethanol fuel included[296,297]:
1) The establishment of a government vehicle fleet that was predominantly ethanol-fuelled;
2) A requirement of a minimum of 20% of ethanol mixed in with gasoline;
3) The establishment of a maximum ethanol price of 65% of the gasoline price; and
4) Tax reductions for ethanol products and ethanol-fuelled vehicles, including for taxi fleets.

[288] Gomes da Cruz et al (2012)
[289] Francisco (2022)
[290] Stattman et al (2013)
[291] Stattman et al (2013)
[292] Gomes da Cruz et al (2012).
[293] Campos and Viglio (2022).
[294] Gomes da Cruz et al (2012)
[295] Campos and Viglio (2022).
[296] Gomes da Cruz et al (2012)
[297] Silveira and Johnson (2016)

Figure 13 A historic overview of national and international trends that shaped the Brazilian innovation system for bio-ethanol. Rectangles depict actors, elipses represent events, while arrows indicate (uni- or bidirectional) interactions.



In addition, the strategy for ethanol-fuelled vehicles focused on campaigns to gain consumers' trust to influence their car purchasing decisions, which included demonstration by "touring" with ethanol fuelled vehicles[298]. This policy package was relatively successful in stimulating demand for ethanol-fuelled vehicles in the early 1980s. In 1985, ethanol-fuelled vehicles accounted for over 95% of total sales of otto-cycled vehicles for the Brazilian domestic market, compared to only 0.5% in 1979. [299,300,301]

Multiple pilot and demonstration projects were developed via multi-stakeholder partnerships in the early 1980s, funded mostly with government funds. For instance, Project Hidrocon was established in 1980 by the Technology Development Company (CODETEC), a partnership between the Secretariat for Industrial Technologies (SIT) from the Ministry of Science and Innovation, the State University of Campinas (UNICAMP) and private company Aços Villares S.A. There were also initiatives from the private sector, most notably the R&D programme from Dedini, an equipment supplier for ethanol distilleries.[302]

At the time, there was no clear predominance of one technological route and activities focused on multiple options. The Brazilian government asked the National Technology Institute (INT) to conduct studies on the development of ethanol from different sources[303]. R&D activities on enzymatic hydrolysis, already initiated in this period, proved important for the emergence of E2G later on. On the other hand, the small-scale production of ethanol from cassava, stimulated as an opportunity for economic development for small-holder farmers in poorer regions, was unable to compete with larger-scale sugar cane-based production and ultimately disappeared[304]. By the end of the period, there was a clear dominance of large-scale sugarcane-based ethanol production.

The years 1986-1995 were a period of stagnation, as the dire economic situation in the late 90s made it very difficult for the government to maintain the fiscal incentives for industrial programmes, including ethanol[305]. A perception of domestic ethanol cars being "inferior" or less "high-tech" than cars from developed countries led to uncertainty about future political support. [306,307]

The "first ethanol shock" in 1989-'90 was partially due to international developments in the oil and sugar markets, which resulted in an ethanol supply shortage in the domestic market.[308] This led to the need to import ethanol to meet increased domestic demand due to the grown ethanol vehicle fleet. This reduced the competitiveness of ethanol fuel and hence the attractiveness of ethanol-fuelled vehicles, with sales dropping from 96% of total sales to 12% between 1985-1990. This, in turn, resulted in a loss of interest from the car industry to produce ethanol-fuelled cars. [309,310]

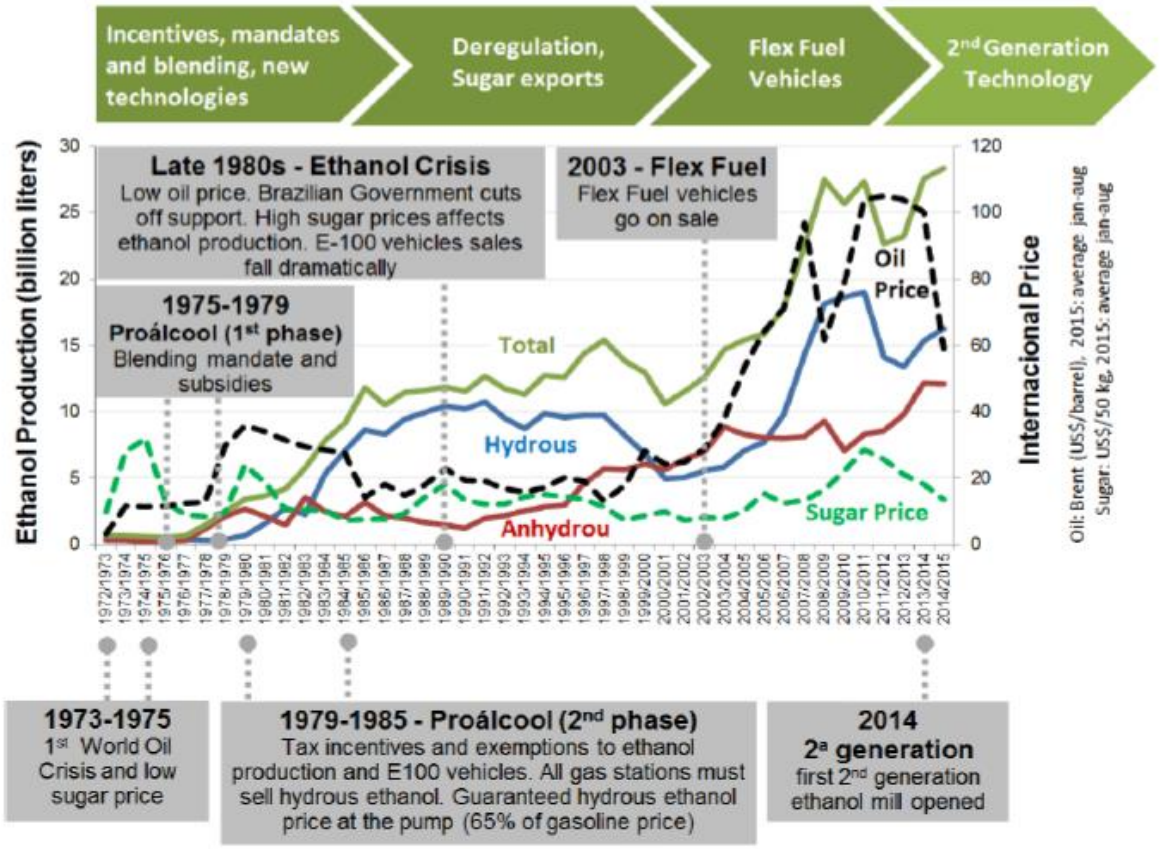
The 1990s led to major changes in the institutional landscape. During ProÁlcool, ethanol competitiveness heavily relied on subsidies and price regulations. When the sector was deregulated in the 1990s and subsidies were removed, ethanol became uncompetitive. Some producers went bankrupt, while others turned to sugar production. Fuel substitution was no longer a priority given the low oil prices, environmental issues were not yet on the agenda, and development concerns took priority during the economic crisis.[311,312] As a result, ProÁlcool ended in 1991 and the Sugar and Alcohol Institute (IAA) was abolished[313], as was PLANALSUCAR[314]. In

[298] Campos and Viglio (2022).
[299] Stattman et al (2013).
[300] Gomes da Cruz et al (2012)
[301] Francisco (2022).
[302] Tete and De Souza (2017)
[303] Tete and De Souza (2017)
[304] Stattman et al (2013)
[305] Francisco (2022)
[306] Stattman et al (2013)
[307] Gomes da Cruz et al (2012)
[308] Campos and Viglio (2022)
[309] Gomes da Cruz et al (2012)
[310] Stattman et al (2013).
[311] Gomes da Cruz et al (2012)
[312] Silveira and Johnson (2016)
[313] Campos and Viglio (2022)
[314] The Interuniversity Network for the Development of the Sugarcane Industry in Brazil (RIDESA) took over the R&D activities from PLANALSUCAR RIDESA (2022). Our history. https://www.ridesaufscar.com.br/historico.

addition, the Ministry of Development, Industry and Trade was closed in 1990. This also terminated the Industrial Technology Department, one of the key institutions promoting technology development under ProÁlcool. This marked the end of the phase where ethanol was driven by Brazil's industrial policy[315].

By the end of the 1990s, the ethanol sector was in crisis, marked by uncertainty and a lack of direction for technical change. This led some businesses to create associations to try and rescue the sector. For instance, the Brazilian Sugarcane Industry Association (UNICA) was established in 1997 and a sugarcane cartel was created to control ethanol prices. However, the stagnation lasted until the establishment of the Flex-Fuel market in 2003[316], described below.

Figure 14: Trends in international sugar, bio-ethanol and oil prices over time [317]



3.4.4.3 The ethanol revival: combining market creation and local sustainable technology innovation support

In the 2000s, energy security concerns due to increasing oil prices and increased international attention for the negative environmental impacts of fossil fuels led to a revival in the Brazilian ethanol innovation system, with bio-ethanol being seen as a solution to both problems. It is possible to identify two separate but complementary processes that strengthened the ethanol TIS in this period.

Firstly, there was the *creation of both a renewed domestic and international market* for ethanol. This contributed to the further development of the Brazilian ethanol TIS through a "demand-pull" effect and helped to increase alignment between the public and private sectors interests, given the expected economic benefits. Domestically, policies and measures included government incentives for anhydrous ethanol, for instance via blend mandates, tax benefits for industrialized goods, and fuel subsidies. The main milestone resulting from these efforts was the

[315] Sousa, L. C. de; Vonortas, N. S.; Santos, I. T.; Toledo Filho, D. F. de (2016): Innovation Systems of Ethanol in Brazil and the United States: Making a New Fuel Competitive. In: Global Bioethanol: Elsevier, pp. 93–121.
[316] Campos and Viglio (2022)
[317] Luís A. B. Cortez, L.A.B. , L.A.H. Nogueira, M.R.V.L. Leal, R. Baldassin Jr. 2016, 40 Years of the Brazilian Ethanol Program (Proálcool): Relevant Public Policies and Events Throughout Its Trajectory and Future Perspectives, 22nd International Symposium on Alcohol Fuels, See: https://bioenfapesp.org/gsb/lacaf/documents/papers/05_ISAF_2016_Cortez_et_al.pdf

introduction of Flex-Fuel Vehicles in 2003.[318,319] Technological development was carried out by three separate companies in the 1990s.[320,321,322,323] Internationally, an increased support for E2G because of increasing sustainability concerns regarding E1G helped create an export market for Brazilian producers. Based on the expectation that ethanol would become more important in Brazil as well as abroad, the private sector increased ethanol production.[324] E2G was identified as a key opportunity for Brazilian exports in a study commissioned by the President's Committee for Strategic Issues (NAE). These expectations around economic opportunities from ethanol production and exports contributed to an alignment of the public and private sectors on their biofuels interests and policies.

Secondly, *overcoming technological bottlenecks* was still needed to meet growing ethanol demand for the expanding vehicle fleet and export markets. Here, government efforts to support technological development, especially improving Brazil's technological leadership in E2G, further contributed to strengthening the ethanol TIS via a "technology-push" effect. In 2005, the Ministry of Science and Technology asked the Centre for Strategic Studies (CGEE) to identify the public policies needed to promote the sustainable expansion of ethanol (the "Ethanol Project"). It recommended providing incentives for cellulosic E2G, increasing public investment in R&D and establishing a centre for research and development to coordinate activities across the different technological routes, and with international developments.[325] As a result, the Brazilian state-owned agricultural research institution Embrapa established a decentralized unit called "Embrapa Agro-Energy" in 2006. This unit resulted from efforts from the agriculture sector to modernize biofuel production technologies.[326]It aimed to:

- Coordinate research activities;
- Assemble existing expertise and create a knowledge centre to become a reference in the country;
- Support the National Agro-Energy Plan; and
- Be the reference centre for coordination with relevant research and innovation networks and consortia.

Moreover, the National Laboratory of Science and Technology of Bioethanol (CTBE) was launched in 2009, with the explicit aim to produce research on industrial technologies for cellulosic ethanol and to create sustainability models for the sector[327]. In addition, Ethanol Project participants joined efforts with Brazilian universities and created a network called "Rede Bioethanol". The network included over 150 researchers affiliated with 15 Brazilian universities and 4 foreign universities, as well as national and multinational companies.[328] Several other R&D Projects were carried out in Brazilian federal universities (UFRJ, UNICAMP and UNB). This was funded by innovation agencies like FINEP and FAPESP, as well as the mandatory 1% of oil & gas company revenues for funding R&D activities. This was possible because bioethanol regulation came under ANP responsibilities in 2011 (see Section 3.4.2). Funds acquired through international cooperation also supported research efforts in this period.[329]

The Joint Plan of Support for Technological Innovation of the Industrial and Chemical Industries using sugarcane (Industrial PAISS) was launched by the Brazilian Development Bank (BNDES) and FINEP in 2011. It aimed to increase coordination between stakeholders (e.g., companies, research institutes and financial organizations), increase participation of the private sector in innovation activities, and increase and consolidate public funding incentives.[330] PAISS led to the establishment of one demonstration plant (by CTC) and two industrial-scale

[318] Gomes da Cruz et al (2012)
[319] Campos and Viglio (2022)
[320] Bosch, Delphi and Magnetti Marelli. The model to first reach the market was the Volkswagen Gol Power 1.6 Total Flex, with a price difference of only U$320 with a conventional gasoline-fuelled vehicle. Several other models followed, including the Fiat Palio, Chevrolet Celta and Fiat Uno Mille.
[321] Silveira and Johnson (2016)
[322] Campos and Viglio (2022)
[323] Stattman et al (2013)
[324] Gomes da Cruz et al (2012)
[325] Tete and De Souza (2017).
[326] Sousa et al (2016).
[327] Sousa et al (2016).
[328] The network jointly applied for research funding for the project "Bioethanol I", which received R$3 million in funding from FINEP in the period 2006-2009. Project "Bioethanol II" followed with a R$9,9 million budget and led to the creation of the "Bioethanol Laboratory" at the Federal University of Rio de Janeiro (UFRJ) in 2013. Tete and De Souza (2017)
[329] Tete and De Souza (2017).
[330] Sousa et al (2016).

production plants (by companies GranBio and Raízen) for E2G. In 2014, these three companies founded the Brazilian Association for Industrial Biotechnology (ABBI), with the aim to increase the legitimacy of E2G in Brazil, to improve industrial biotechnologies regulations, discuss sector policies and incentives, promote knowledge development by partnering with science and innovation institutes, and to coordinate knowledge diffusion in the sector.[331] In 2014, an agricultural version of PAISS was created to foster the development of agricultural machinery for ethanol production.[332]

Text Box 1 Decarbonisation credits for biofuel supplies under RenovaBio

Under RenovaBio, national GHG emission reduction targets are broken down into mandatory individual targets for individual fossil fuel distributors, in proportional to their market share. To meet their reduction targets, fuel distributors need to buy a set amount of Decarbonisation Credits (CBIOs[333]). These credits are generated by biofuel producers and importers, based on their purchase and sale invoices. Different grades are assigned to each biofuel producer and importer through the Biofuel Certification and the Energy-Environmental Efficiency Rating (NEEA) system. Producers get higher grades if they produce higher amounts of net energy, with lower CO_2 emissions, throughout the lifecycle. This process of certification allows producers and importers to generate CBIOs, which are equivalent to one ton of carbon. They are valid for three years and need to be issued by inspecting firms accredited by ANP. The certificates are registered by financial institutions and can be traded on the Stock Exchange.

Various factors led to a situation where E2G was developed mainly targeting exports, especially to the United States[334]. This included technological problems in E2G production, leading to uncompetitive prices in the domestic market[335], a lack of specific demand for E2G in the domestic market and strong policies for E2G use in other countries. Therefore, at this point, there was a need to also create a domestic market specifically for E2G. The earlier policies did not impact E1G and E2G in a similar way, as the latter was not yet as mature and competitive as the former. Hence, in 2014, the ANP regulation was updated to recognize E2G as a fuel to be used in the Brazilian energy mix. This guaranteed access of E2G to the Brazilian market. This was further supported by the inclusion of climate change-related concerns in the national biofuel policy RenovaBio in 2017 and the establishment of GHG emission reduction targets for the national fuel mix for the period 2019-202[336]. This helped manage expectations and reduce uncertainty in future ethanol demand, while rewarding low-carbon ethanol production routes through the implementation of carbon reduction credits (CBIOs, see Text Box above).[337]

3.4.5 Assessment of the initiatives

Knowledge development and diffusion Several initiatives in the Brazilian ethanol innovation system contributed to knowledge development across the entire value-chain: from improvement on sugarcane production, to ethanol production, to development of ethanol-fuelled cars for ethanol use. Multi-stakeholder partnerships and organizations like ECCP[338], IDESA[339], CTC, the government, research networks and industry associations contributed to strengthening coordination between actors, align expectations and promote knowledge sharing and diffusion. An active role of the government in supporting efforts to achieve technology leadership globally resulted in many of the initiatives also having an industrial development component, explicitly aiming to strengthen local industry. As a result of these efforts and collaborations, gaps in the NIS related to fragmentation between knowledge production, which were overcome by the ethanol TIS. Collaboration with international actors (e.g. multinational companies, foreign researchers) have also had an important role in knowledge development and diffusion, for instance via international research networks.

[331] Tete and De Souza (2017).
[332] Sousa et al (2016).
[333] Certificates of Efficient Production of Biofuels
[334] Sousa et al (2016)
[335] Tete and De Souza (2017)
[336] In CNPE resolution No.15 of June 2019
[337] Grangeia et al (2022)
[338] European Cluster Cooperation Platform, an online hub for industry clusters with the aim to strengthen the European economy through collaboration, see: https://clustercollaboration.eu/
[339] the Interuniversity Network for the Development of the Sugarcane Industry in Brazil

Entrepreneurial experimentation Experimentation was kick-started early on from the bottom up in the private sector, by sugarcane producers aiming to diversify their business. Through the decades, organizations from the public and private sector, as well as from academia, further promoted experimentation, often in collaboration with each other. Important examples are ECCP, CTC, GranBio, Raízen, Dedini, as well as federal universities. Experimentation through multi-stakeholder partnerships (including academia, government and the private sector) were key for strengthening coordination, sharing knowledge and mobilizing funding for experimentation. It also increased interaction between knowledge producers and users, making learning from experimentation more dynamic. Programmes like the Technology Innovation Partnership Programme (PITE) and the Industrial PAISS were key facilitators for the establishment of demonstration plants.

Market formation Market formation was a crucial function for the success of the ethanol innovation system in Brazil, especially after the 2000s. Domestic market formation was achieved mainly via regulations that established minimum requirements for blending ethanol into gasoline, as well as measures to stimulate the introduction of ethanol-fuelled vehicles such tax incentives and public procurement. The introduction of FFVs was a major driver for domestic ethanol demand, with the market share of hydrous ethanol increasing from 4% in 2003 to 15% in 2019.This policy is widely considered a milestone in the development of the ethanol TIS in Brazil, since it specifically allowed the establishment of a solid domestic market for ethanol fuel by creating a "demand-pull" effect.

One of the reasons why this policy was considerably more successful than previous efforts was that it contributed to overcome the resistance against (exclusively) ethanol-fuelled vehicles caused by the ethanol shortages in the early '90s: The engine provided consumers the flexibility to choose between using gasoline and ethanol, e.g. based on their availability and prices.[340,341,342,343] Another success factor of FFVs implementation was that it was well tailored to the Brazilian socio-economic context since it targeted "economic car models"[344], which accounted for 38% of total sales at the time of the introduction of the policy and over 90% in 2013. This allowed the share of FFVs to rapidly grow and achieve over 70% of the total vehicle fleet in Brazil in 2017. This also applied to Flex-Fuel motorcycles, introduced into the market in 2009 and accounting for around 50% of motorcycle sales in 2016. [345,346,347]

There were also international developments that contributed to the formation of an export market for ethanol fuels, though mainly for E2G. Following the signature of the Kyoto Protocol, increasing concerns about the sustainability of available biofuels pushed countries to establish policies to promote more sustainable biofuels, creating an opportunity for Brazilian ethanol producers. This was especially important as the domestic market back at the time did not provide the conditions for E2G to become competitive. An E2G domestic market ramped up more recently after the establishment of national targets for GHG emission reduction and the implementation of carbon credits after the establishment of the new biofuels strategy RenovaBio. It should be noted that RenovaBio and the emission reduction targets were part of the country's implementation of the Paris Agreement, again showing how the international context influenced the local ethanol TIS.

Influence on the direction of the search Alignment between the productive sector, government, academia, as well as users was a key factor in the development of the ethanol industry in Brazil. External factors like international market crises, wars, etc also played a role by highlighting structural dependencies of the Brazilian economy. A strong sugarcane industry was paramount for establishing the ethanol technology route based on sugar cane. T*his, however, also highlights risks related to path-dependencies in innovation. The ethanol route in Brazil was influenced by the economic and social structure in place existed at the time in the form of the large-scale sugarcane industry. This provided an advantage in terms of leveraging existing production and innovation capabilities It also meant that other routes that could not build on this existing "stock" of capabilities were unable to compete. Notably, smaller-scale cassava-based ethanol production routes, seen as an opportunity for*

[340] Gomes da Cruz et al (2012)
[341] Campos and Viglio (2022)
[342] Silveira and Johnson (2016)
[343] Stattman et al. (2013)
[344] i.e. priced under U$10,100 in 2005.
[345] Silveira and Johnson (2016)
[346] Campos and Viglio (2022)
[347] Stattman et al (2013)

supporting economic development for small-holder farmers in poorer regions, ended up disappearing as they could not compete with the larger-scale, more industrialized sugar cane-based production[348].

Resource mobilization Several actors contributed to resource mobilization through the development of the ethanol sector in Brazil. Early on, public and private sector resources were mobilized for sugarcane producers to experiment with ethanol production. Overtime, there were multiple public incentives for ethanol-related innovations, production and use for instance through R&D funding, subsidies to make ethanol prices competitive, as well as tax exemptions, under national programmes such as ProÁlcool and PAISS. Public innovation funds like FINEP and FAPESP349, state-owned enterprises like Coalbra and Petrobras, as well as the national development bank BNDES were key in mobilising funding for RD&D projects. This mobilization of public funding allowed for the availability of long-term patient capital and often also contributed to reduce risks for private investors. ANP's 1% clause also ensured availability of funds for RD&D projects in companies from the energy sector. Moreover, private technology suppliers like Dedini, GranBio, Raízen, but also cooperatives like CTC, also mobilised resources. International cooperation also provided support. Importantly, resource mobilization did not happen by individual actors only, but it was often done via partnerships.

Legitimation Several regulations in the form of decrees establishing minimum blends of ethanol into gasoline and establishing ethanol as a fuel in its own right helped legitimate the introduction of ethanol in the Brazilian transport fuel mix. Research networks and industry associations contributed to support the legitimacy over the decades by coordinating with government and emphasizing the importance of the fuel to the national economy. Word of mouth among consumers was an important factor for the legitimacy of ethanol-fuelled vehicles. The introduction of Flex-Fuel Vehicles provided consumers with the flexibility to choose between ethanol and gasoline, overcoming resistance to ethanol-fuelled vehicles. Moreover, international events such as the adoption of the Kyoto Protocol and the Paris Agreement, together with developments for E2G in the United States, increased the legitimacy of specifically E2G in Brazil.

Development of positive externalities The development of the ethanol sector in Brazil has always been very closely linked to broader goals of economic development and industrial policy. Initially, it helped to diversify income for the sugarcane industry, later it helped develop a local industry for Flex-Fuel Vehicles, as well as ethanol production equipment manufacturers and service providers. These stakeholders created associations and networks to advocate for even further government support to the technologies involved. Energy security and affordability were also key goals behind governmental ethanol policies , as it would enable Brazil to become less dependent on oil imports and hence less vulnerable to external shocks. Consumers could benefit from lower fuel costs by being able to choose cheaper fuels with the introduction of FFVs. This helped increase popularity of the fuel on the user side. The expectation of economic benefits from E2G exports contributed to the alignment of interests between the private and the public sectors around the promotion of E2G, resulting in a substantial acceleration of innovation and development in this technological route in the early 2000s. Environmental externalities have been a strong incentive for the development of a market for E2G, firstly abroad but later also domestically.

Table 10 summarizes the structure-function coupled analysis of Brazil's bio-ethanol activities.

[348] Stattman et al (2013)

[349] São Paulo Research Foundation, a public foundation, funded by taxpayers in the State of São Paulo.

Table 10 Structure-function-coupled analysis of bio-ethanol activities in Brazil

Function		Structural element	Interventions in the Brazilian ethanol innovation system
F1	Knowledge develop-ment and diffusion	Actors	• Many actors contributed to knowledge development and diffusion. These actors were also varied in type, including cooperatives (e.g., Copersucar's R&D center Sugarcane Technology Center (CTC)), private companies (Dedini, BIOBRAS, Coalbra, GranBio, Raízen), public universities and knowledge institutes (e.g., UNICAMP, UFRJ, UNB, National Technology Institute (INT) & National Laboratory of Science and Technology of Bioethanol (CTBE)), government entities like the Secretarial for Industrial Technologies (Ministry of Science and Innovation). The interuniversity Network for the Development of the Sugarcane Industry in Brazil (RIDESA) contributed to knowledge sharing and diffusion. International cooperation (international congresses, networks of scientists, collaboration between companies, technical assistance, etc.) also played a role
		Institutions	• Many policies and regulations contributed to promote knowledge development and diffusion, e.g. the PLANALSUCAR and ProÁlcool programmes The ANP regulation requiring 1% of companies' revenues to be invested in R&D ensured availability of funding for knowledge development.
		Interactions	• Multi-stakeholder partnerships and networks played an important role in promoting knowledge development and diffusion, especially by allowing knowledge producers and users to learn by interacting. Key examples are the ECCP networks in the 1920s, later IAC, CTC, as well as RIDESA, networks of university researchers like Rede Bioethanol and collaboration with foreign universities under the "Bioethanol Projects I and II"
		Infrastructure	• As a result of knowledge development, sugarcane productivity improved • By upgrading its own competences and learning from imported materials, Dedini created a local equipment manufacturing and service industry
F2	Entrepre-neurial experi-mentation	Actors	• Private sector entrepreneurs from the sugarcane sector were the first to start experimentation with ethanol technologies. EECP also experimented with sugarcane varieties in the 1920s and many demonstration programmes were implemented through multi-stakeholder collaborations over the years. Experimentation by companies like Dedini, Raízen, GranBio were key for developing a local technology supply industry
		Institutions	• Many policies favored experimentation, making public funding available for early experimentation as of the 19th century. Later, e.g. the Technology Innovation Partnership Programme (PITE) and the Industrial PAISS were key examples in incentivizing entrepreneurial experimentation
		Interactions	• Since many of the experimentation initiatives involved a multiplicity of stakeholders, the interaction between these actors improved not only resource mobilization for experimentation, but also allowed for learning by doing/interaction to be accelerated. Lessons learned from these experimentations could then more easily be incorporated in the producer and user sectors. Examples are the EECP coordinating role between scientists and sugarcane producers, the role of the Brazilian Sugarcane Industry Association (UNICA), and the Dedini-CTC-FAPESP partnership
		Infrastructure	• Dedini's experimentation plants and three demonstration plants for E2G are some examples of infrastructure that supported experimentation
F3	Market formation	Actors	• Government coordinating with automobile industries and establishing public policies for stimulating demand, including public procurement • Automobile industries developing Flex-Fuel Vehicles
		Institutions	• Many policies, regulations contributed to domestic market formation, including mandates for compulsory addition of ethanol to gasoline, public procurement for ethanol (and FFVs) vehicles, fiscal incentives and financial loans to develop ethanol-fueled vehicles under ProÁlcool, price regulation to avoid competition with gasoline, purchase guarantees from Petrobras, stimulating ethanol use in chemicals production via ProAlcool • International agreements like the Kyoto Protocol and the Paris Agreement contributed to increased concerns about GHG emissions and sustainability. This led to countries implementing policies for sustainable biofuels, which in turn created a market for exports of Brazilian E2G
		Interactions	• The government played a key role in engaging sugar producers, the automobile industry and the oil & gas sector (mainly via Petrobras), helping to align expectations and coordinate action to allow for the ramp up of the ethanol market in Brazil
		Infrastructure	• Infrastructure of oil & gas was used to transport and distribute once Petrobras bought ethanol from producers
F4		Actors	• The Brazilian government helped provide direction of the search via national strategies/policies, especially by considering the ethanol industry an "industry of national interest"

	Influence on direction of search		• Institutes like the National Technology Institute (INT), the Committee for strategic issues (NAE) and the Centre for Strategic Studies (CGEE) helped to align expectations through studies about ethanol technologies, including from multiple production routes.
		Institutions	• Government policies aligned expectations for future of ethanol technology (and market) development, also by help setting standards, regulations • International agreements as well as policies in other countries contributed to a reprioritization between E1G and E2G
		Interactions	• International cooperation (Soviet Union, scientific networks, company collaborations, regulations in other countries e.g. US for 2G ethanol) • Lobby from industries since the 1920s helped influence government policies in certain directions
		Infrastructure	• A strong sugarcane industry, allowing for a more favorable starting point for sugarcane-based ethanol production
F5	Resource mobilization	Actors	• Public funding was a main source for resource mobilization, via government subsidies, public R&D funding (FINEP, FAPESP, FINEP, BNDES) • Additionally, private funding was mobilized via e.g., private R&D institutes, technology suppliers, and manufacturers. This included private companies like Dedini, GranBio, Raízen, but also cooperatives like CTC, as well as car manufactures
		Institutions	• Many policies and regulations contributed to resource mobilization, especially the ANP 1% R&D regulation and the Industrial PAISS
		Interactions	• Collaboration between private sector, university and government funding institutes was widely present in RD&D projects
		Infrastructure	• The use of existing infrastructure in many cases (part of sugar production, gasoline distribution, etc.) meant ethanol did not require the creation of entirely new infrastructure, helping to reduce the need for resources
F6	Legitimation	Actors	• Sugarcane producers were key legitimizing ethanol by advocating it as an important solution to economic dependency and energy security risks • Government promoted legitimation, e.g. by introducing mandatory blending requirements early. Recognition of ethanol as an industry of national interest and as part of broader socioeconomic priorities contributed to increase support from industry and create jobs.
		Institutions	• Introduction of an ethanol fuel variety in 1927 was the first policy to contribute to ethanol to be seen as a “legitimate fuel” in Brazilian fuel mix • Public campaigns for ethanol vehicles aimed to increase awareness and overcome resistance
		Interactions	• Scientific meetings helped share information on best available knowledge on ethanol technology development, leading to recognition of progress • Word of mouth of consumers from ethanol fueled vehicles and FFVs helped to build (and unbuild) trust in the technology
		Infrastructure	• Dependency on imported gasoline and commodity exports increased vulnerability to external shocks, increasing legitimacy of ethanol production
F7	Develop-ment of positive externalities	Actors	• Companies in sugarcane, automobile and energy sectors could benefit economically from ethanol development, motivating them to support policies • Government recognizing ethanol as industry of national interest created opportunities for industrial development, job creation, hence more support • Consumers could save money by choosing between ethanol and gasoline depending on prices due to the flexibility from FFVs
		Institutions	• ProÁlcool was part of the national development plan, explicitly aiming to promote national economic development and industrialization, as well as to increase energy security and affordability • Introduction of Flex-Fuel Vehicles created a local industry that not only was able to increase economic benefits, but also created jobs in the sector • The support under PAISS helped to establish three of the main technology suppliers in ethanol technologies in Brazil • The policy RenovaBio creates positive environmental externalities by incentivizing GHG emission reduction via carbon credits and reduction targets
		Interactions	• Industries benefiting from ethanol created associations to coordinate action and lobby for ethanol • The Rede Bioethanol would advocate for improving ethanol technology to reduce environmental impacts
		Infrastructure	• Employment creation in the industry • Development of technological routes with lower environmental impact

3.4.6 Role of the initiative in Brazil's NDC

Biofuels play an important role in Brazil's energy mix. According to the IEA Bioenergy Technology Cooperation Programme (TCP)[350], biofuels represented 25% of transport fuels in Brazil in 2021, which is a very high share compared to other countries. Among biofuels, ethanol is the most important, with 49% of the energy use from gasoline and ethanol combined. Biofuels are a key to reducing transport emissions.[351] The National Biofuels Policy (RenovaBio) was established in 2017 with the explicit aim of contributing to the implementation of the Brazilian NDC, as well as to energy security. It hence sought to increase the share of biofuels in the energy mix[352] and reduce the carbon intensity of the transport fuel matrix by 10% and avoid 620 million tonnes of CO_2-eq emissions from 2018 until 2030[353].

In contrast to previous policies, RenovaBio explicitly values the environmental externalities of biofuels production and use. It aims to promote the expansion of biofuels in the Brazilian energy matrix by providing incentives to biofuel producers. It has provisions for the commercialization of the fuel market and increasing its predictability, and proposes the creation of a market for carbon emission reduction credits (CBIOs). However, this policy is relatively recent, so the actual long-term contribution of RenovaBio to the Brazilian NDC is still to be seen. In addition, some issues related to the detailed accounting methodology and some legal and regulatory aspects are still to be defined (2021.[354]

The development of biofuels, including ethanol, has also contributed to other sustainable development goals in Brazil. For instance, it has promoted job creation and income generation in ethanol production, but also throughout the value chain, e.g. in sugarcane production and FFV manufacturing., In 2019, ethanol production is estimated to support around 1.5 million direct and indirect jobs in the country according. Moreover, development of an ethanol industry in rural areas can lead to positive impacts on local infrastructure, supporting livelihoods in the surrounding areas.[355]

3.4.7 Key success factors and lessons learned

For successful innovation, both technology-push and technology-pull policies are needed. The case of ethanol in Brazil shows the effectiveness of having both policies aiming to further develop the technologies (technology push, e.g. incentives for RD&D), and policies that reduce demand risks by creating a market for the product (for instance via quotas, public procurement, incentives for ethanol use in vehicles). This could be clearly seen for both E1G and E2G. While RD&D played a key role for learning and improvement in the first decades, the establishing of minimum blending shares and the introduction of FFVs reduced demand uncertainties for ethanol producers. Moreover, while government policies and incentives in the 2000s enabled the acceleration of technology development for E2G, it was the creation of export markets that prompted both private investors and the government to increase efforts due to expected future economic opportunities.

Innovation policies and coordination are needed across the value chain. The development of ethanol in Brazil was strongly facilitated by simultaneous incentives and coordination from sugarcane production to ethanol production to ethanol use in the transport sector. For each of these steps in the value chain, both technology-push and demand-pull policies were implemented. Government played a key role in promoting coordination and collaboration between the actors involved, in order to avoid actors waiting for others to make the first move to reduce their own risks.

[350] IEA Bioenergy is a TCP set up in 1978, aiming to improve cooperation and information exchange between countries with national programmes in bioenergy RD&D. TCPs are independent bodies operating in a framework provided by the IEA. There are 42 currently active TCPs. See: https://www.ieabioenergy.com/about/
[351] IEA Bioenergy (2021) Country reports: Implementation of bioenergy in Brazil – 2021 update. Available at https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Brazil_final.pdf
[352] Grangeia et al (2022).
[353] IEA Bioenergy (2021)
[354] Grangeia et al (2022)
[355] IEA Bioenergy (2021)

A mix of bottom-up and top-down measures facilitate innovation. The ethanol system in Brazil was developed by a mix of bottom-up initiatives, led mainly by the private sector and academia, with top-down measures from government. While the private sector and academia initiatives were crucial in enabling experimentation with different technological routes, ensuring support from stakeholders, and facilitating learning, this was not enough to make ethanol competitive as a fuel by itself. Top-down measures helped achieve this by introducing purchasing quotas, price caps, minimum blend requirements, as well as by ensuring coordination across sectors and reducing uncertainty by clearly making long term commitments to an industry that was officially designated "an industry of national interest".

Coordination between knowledge producers and users accelerated diffusion. The experimentation with ethanol development in Brazil saw the establishment of several multi-stakeholder networks and partnerships that ensured coordination and feedback between technology development and use. This allowed for greater dynamism and a faster uptake of lessons learned in production, accelerating technology development and increasing productivity.

Aligning technological development with societal goals facilitates the formation of coalitions that provide political support and legitimacy to new technology. Since the development of the ethanol sector was always linked to other societal goals, such as reducing international economic dependency for fuels and commodities and promoting energy security and employment opportunities, policies for ethanol promotion enjoyed relatively high political support and social acceptance. The flexibility provided by FFVs allowed consumers to choose fuels according to relative prices, increasing affordability, and hence overcoming resistance on the user side. More recently, environmental sustainability concerns were a major factor for the increase support to E2G.

Innovation takes time, is uncertain and highly dynamic. Despite the overall success of the ethanol sector in Brazil, several projects and initiatives failed over the years. Early stages faced high uncertainties regarding technological routes, but also about potential unforeseen impacts on other societal goals. Ethanol was initially developed due to economic and energy security concerns, but ended up helping with climate change mitigation goals. The expansion of ethanol production also has had unforeseen negative impacts, such as on food production, population displacement and deforestation. All of these became evident only later on. This highlights the need for continuous monitoring and evaluation of innovation and technology development to ensure alignment with changing societal goals and emerging insights.

International aspects can influence the development of local innovation systems, intentionally or not. Local support for technology innovation as well as early market formation increased Brazil's ability to compete in international markets. Firstly, the development of an ethanol industry started due to a crisis in the global sugar market. World wars provided an extra push for developing a local industry due to difficulties in importing goods such as equipment for ethanol production. More recently, environmental policies in the US created the demand for E2G in Brazil. International cooperation within networks of firms and researchers were an important mechanism for knowledge development and diffusion. However, even though these international events created opportunities for ethanol development, it was the local government and entrepreneurs that ensured that this was seized. Without local support, technology leadership would not have been achieved, even with the international context created favourable conditions. In fact, these international "favourable conditions" initially led to a situation, where more environmentally sustainable products were exported, with less sustainable products ending up at the domestic market. Government intervention through the RenovaBio policy helped change this.

Capabilities are needed across all stakeholders. The case of the ethanol sector in Brazil highlights that different types of capabilities are needed by different types of stakeholders. For instance, appropriate scientific and technological capacity helped to ensure a knowledge base to promote technological development and learning. An appropriate business base, from existing firms and entrepreneurs was crucial to develop production capabilities. In addition, knowledge within public organizations formulating and executing policies was required. Finally, user capabilities for instance in terms of understanding the advantages of FFVs were crucial for creating the demand for ethanol.

International cooperation in innovation and technology transfer, in many forms, was crucial in all phases of ethanol development in Brazil. Networks of scientists, cooperation between local and international/multinational firms, as

well as government-led visits to other countries were an important mechanism for knowledge development and diffusion. Local manufacturers were able to learn from imported equipment to start manufacturing their own versions. However, it should be noted that intellectual property rights regimes were less strict than in today's world.

3.4.8 Good practices for potential replication

Based on the above lessons learned from the ethanol sector in Brazil, the following good practices can be identified that could lend themselves for replication in other countries:

Ensure continuous monitoring and evaluation, providing room for realignment if needed. As new knowledge is produced or societal goals change, it is important to assess whether innovation policies are still fit-for-purpose. Conditions may also change over time, and some technology options that were not attractive earlier may become a good solution later on. Clearly seen with the different evolution of E1G and E2G in Brazil, this can also be a lesson for other technologies and countries.

Strengthen networks to ensure coordination between stakeholders. Strong networks facilitate knowledge development and diffusion across the system and help overcome coordination failures. It helps align expectations and provide a direction to technological change. Closer collaboration between knowledge producers and users makes incorporation of lessons learned more dynamic and accelerates progress.

Facilitate a combination of top-down and bottom-up measures. Bottom-up initiatives enjoy high levels of ownership from stakeholders as they are more likely to reflect the variety of stakeholders' interests, needs and concerns, e.g. local producers to conduct entrepreneurial experimentation to find opportunities for income diversification. However, bottom-up initiatives in their own are usually not enough to make innovations competitive in existing markets, as the new technologies or products can face higher levels of uncertainty and fragmentation. Top-down measures are required to provide guidance, reduce uncertainty, establish more favourable regulations and ensure coordination between actors from multiple sectors and across the entire value chain.

Ensure policies address both technology-push and technology-pull aspects. Innovation policies should promote the development of new technologies by investing for instance in R&D. However, new technologies are often unable to compete with established technologies, or are not yet integrated into the system regulations. Proactive policy making can ensure that there is a demand for innovations in the market, for instance through public procurement and incentives for users.

Strengthen international collaboration and coordination to strengthen mutual opportunities. National policies and initiatives can impact innovation in abroad, just like international developments impact the local innovation system. This is very clear for the ethanol TIS in Brazil, to a large degree developed as part of a response to international developments in the sugar and oil markets, and (for E2G) to policies and regulations for more sustainable biofuels around the world. As a result, many countries import ethanol from Brazil today, thereby benefitting from the results of Brazilian national policies and initiatives over the past century. This situation where policies in one country contribute to strengthen innovation systems in other countries is also known for other cases, such as the case study on the wind energy sector in Denmark (see Section 3.6). Knowledge sharing via transnational networks plays a role in this. However, this should not be about technical aspects alone, but also about e.g., policies and regulations that can promote certain innovations. International cooperation can play an important role in facilitating collaboration in technology innovation, development and transfer. It is however crucial that knowledge is transferred and adapted to the local context.

Strengthen stakeholder capabilities across multiple dimensions. Different actors require different capabilities for contributing to innovation. Capabilities need to be built across the whole set of stakeholders: researchers, producers, users, consumers, and policy makers.

Transform challenges into opportunities for achieving multiple societal goals. Bioethanol development in Brazil was constantly driven by the need to address societal challenges related to energy security, industrial development barriers and economic vulnerability to external shocks. These societal goals contributed to increased private sector and public support for ethanol production and use, resulting in pressure for more supportive government policies and regulations. Such policies subsequently created opportunities to achieve additional societal goals, such as job creation and GHG emission reduction. Such feedback loops can lead to synergies in achieving different societal goals, as also illustrated in the case of the wind energy sector in Denmark. This is especially important in the context of achieving the multiple goals entailed in sustainable development.

3.5 CASE: URBAN FLOOD MANAGEMENT IN JAKARTA

Country	Indonesia	**Focus**	Adaptation
Scope	Urban flood management	**Key innovation system functions**	F1 Knowledge development and diffusion F5 Resource mobilization
Approach	Top-down and bottom-up	**Starting year**	1970s

3.5.1 Introduction to the Initiative

Urban water management aims to establish a sustainable urban water system, providing safe drinking water, handling wastewater, protecting against floods and alleviating the effects of pollution[356]. 'Urban flooding', flooding in urban centers, is caused by rainfall overwhelming the capacity of drainage systems. While this can result from disastrous events such as flash floods, it is usually repetitive in nature, causing systemic impacts on local communities[357]. Overflow may damage infrastructure as well as public and private buildings, seeping through walls and floors or backing up into buildings through sewer pipes. For coastal cities, flood management can also include protection against flooding due to rising sea levels caused by climate change and land subsidence, primarily due to excessive extraction of groundwater.[358,359]

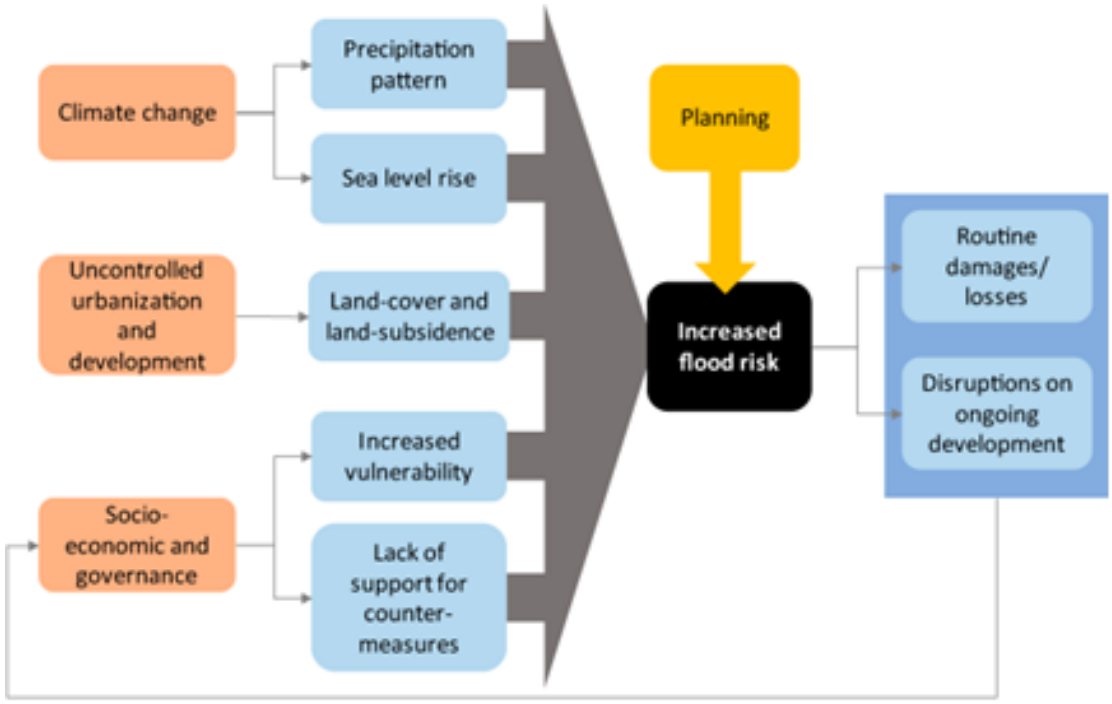
Urban flooding can pose a severe development challenge. Although flooding can be disastrous for both rural and urban areas, flooding in urban regions has more large-scale impacts and is more expensive to manage because of the greater concentration of population and assets.[360] The problem is particularly significant in some of the fast-developing South Asian cities as a burgeoning population, strong economic growth, and unplanned urban development interact with the natural flow of water and various structural, natural, and socioeconomic factors. Many South Asian cities get severely waterlogged (and flooded) during short-duration, high-intensity rainfall episodes[361]. The problem gets amplified in coastal cities where intense rainfall events are frequent and together with local land subsidence and sea level rise, lead to coastal land loss. Some of the regions hosting booming coastal South Asian cities, such as Ho Chi Minh City (Vietnam), Chittagong (Bangladesh), Ahmedabad (India), and Jakarta (Indonesia) are sinking faster than most other regions in the world.[362]

Jakarta is a clear example of a city facing the risk of urban flooding. As the capital and largest city of Indonesia, with a population of over 11.1 million (as of 2022), it is one of the most populous coastal cities in the world[363]. Frequent flooding has been a critical challenge for Jakarta for hundreds of years[364], which is only expected to worsen over time (see Text Box 2). As a result, flood management has been on the national and local government's agenda since the

[356] Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. *Science*, *352*(6288), 928-933.
[357] Center for Neighborhood Technology, Chicago IL, "The Prevalence and Cost of Urban Flooding", May 2013.
[358] The soft soil beneath the city is held together by the pressure of groundwater; however, extreme extraction of the underground water reduces this pressure, and consequently, the land above it subsides.
[359] Sakdapolrak, P., Butsch, C., Carter, R. L., Cojocaru, M. D., Etzold, B., Kishor, N., Lacambra, C., Reyes, M.L. & Sagala, S. (2008). The megacity resilience framework. *Resilience and Social Vulnerability*, *10*. https://www.researchgate.net/profile/Hans-Georg-Bohle/publication/305391391_Megacities_Resilience_and_Social_Vulnerability/links/578ca19608ae254b1de843d4/Megacities-Resilience-and-Social-Vulnerability.pdf#page=12
[360] Jha, A. K., Bloch, R., & Lamond, J. (2012). Cities and flooding: a guide to integrated urban flood risk management for the 21st century. World Bank Publications.
[361] Pervin, I. A., Rahman, S. M. M., Nepal, M., Haque, A. K. E., Karim, H., & Dhakal, G. (2020). Adapting to urban flooding: a case of two cities in South Asia. *Water Policy*, *22*(S1), 162-188.
[362] Tay, C., Lindsey, E. O., Chin, S. T., McCaughey, J. W., Bekaert, D., Nguyen, M., ... & Hill, E. M. (2022). Sea-level rise from land subsidence in major coastal cities. *Nature Sustainability*, 1-9.
[363] see: https://worldpopulationreview.com/world-cities/jakarta-population
[364] https://www.nationalgeographic.com/environment/article/indonesias-giant-capital-city-is-sinking-can-the-governments-plan-save-it#:~:text=Jakarta%20is%20now%20sinking%20at,of%20an%20inch%20a%20year

1970s. [365] This case study assesses key strategies adopted by the city to manage recurring floods. This includes infrastructure-focussed initiatives such as the National Capital Integrated Coastal Development master plan and the Great Sea Wall Project and the normalisation and naturalisation of rivers and the relocation of communities. We also describe non-structural, community-centered initiatives, including Early Warning Systems (EWS) and flood control systems using the Internet of Things (IoT) and artificial intelligence (AI).

Figure 15 Underlying causes and problems that contribute to the increase in flood magnitude in Jakarta[366]



Although Jakarta's flood management experience shows both strengths and weaknesses, it has useful lessons to share. Its flood management projects have had significant material and political effects and an analysis of the experience can lead to enriching insights into the policy-making processes.[367]

[365] Simanjuntak, I., Frantzeskaki, N., Enserink, B., & Ravesteijn, W. (2012). Evaluating Jakarta's flood defence governance: the impact of political and institutional reforms. *Water Policy*, *14*(4), 561-580.
[366] Based on a study by Rahayu, H. P., & Nasu, S. (2010). Good practices of enhancement early warning system for high populated cities: a case study for Jakarta flood) (Adapted from Rahayu, H. P., Haigh, R., Amaratunga, D., Kombaitan, B., Khoirunnisa, D., & Pradana, V. (2020). A micro scale study of climate change adaptation and disaster risk reduction in coastal urban strategic planning for the Jakarta. International Journal of Disaster Resilience in the Built Environment, 11(1), 119-133).
[367] Colven, E. (2020). Thinking beyond success and failure: Dutch water expertise and friction in postcolonial Jakarta. *Environment and Planning C: Politics and Space*, *38*(6), 961-979.

Text Box 2 Factors behind Jakarta's recurrent and severe flooding[368,369,370]

Jakarta experiences both riverine (pluvial) and coastal flooding during the rainy season.[371] The frequency and intensity of the floods and the scale of direct and indirect socioeconomic impacts[372] have increased significantly in the past few decades[373, 374,375] and are expected to multiply in future years.[376,377] The surge in flooding is driven by several natural and socioeconomic factors:

Natural factors

Among the natural factors, the geography and topography of Jakarta are dominant.[378] The city is situated in an alluvial, low-lying, flat coastal region[379] at the mouth of the Ciliwung river, which serves as an inlet of the Java Sea.[380] The Ciliwung is a canalized river over 100 km long that traverses the city and ultimately flows into Jakarta Bay, predisposed to backwater flows from the Java sea during high tides or raised sea levels.[381] The deltaic plain of Jakarta is crisscrossed by 13 natural and artificial rivers, which form the main drainage system of the city.[382] Due to the passage of so many rivers, the city has historically been swampy[383]. In addition, sediments from upstream are deposited here, resulting in limited drainage and storage capacity in Jakarta's rivers. Moreover, the relentless dumping of city waste has further congested the river systems.[384] Jakarta has a tropical monsoon climate with an annual rainfall of more than 1700 mm[385], increasing to over 3000 mm in the Ciliwung watershed, particularly in the upper tracts. Extreme rainfall events are rampant.[386] The increased frequency of extreme rainfall events due to climate change has compounded the problem further[387]. The topography of the city is almost flat, with only around 25m height gain between the highest and lowest points across the city.[388] While climate change-induced sea level rise has made the situation worse for many major coastal cities, Jakarta

[368] Budiyono, Y., Aerts, J. C., Tollenaar, D., & Ward, P. J. (2016). River flood risk in Jakarta under scenarios of future change. *Natural hazards and earth system sciences*, *16*(3), 757-774.

[369]Texier, P. (2008). Floods in Jakarta: when the extreme reveals daily structural constraints and mismanagement. *Disaster Prevention and Management: An International Journal*.

[370] Asdak, C., & Supian, S. (2018). Watershed management strategies for flood mitigation: A case study of Jakarta's flooding. Weather and climate extremes, 21, 117-122.

[371] Betteridge, B., & Webber, S. (2019). Everyday resilience, reworking, and resistance in North Jakarta's kampungs. *Environment and Planning E: Nature and Space*, *2*(4), 944-966.

[372] In recent times, the first major flooding event was in 1996, during which 20-30% of Jakarta was flooded, and the second was in 2002 when 40-50% of the city was flooded (Lassa et al., 2013). The 2007 floods were the most severe event in recent years; around 75% of the city was inundated, leading to a severe loss of life and property (Texier, 2008). Around 450,000 people were displaced, and the economic losses were to the tune of USD 900 million(Mohsin, 2015).

[373] Budiyono et al. (2016)

[374] Hellman, J. (2015). Living with floods and coping with vulnerability. *Disaster Prevention and Management*.

[375] Asdak and Supian (2018)

[376] Budiyono et al. (2016)

[377] Januriyadi, F., N., Kazama, S., Riyando Moe, I., & Kure, S. (2018). Evaluation of future flood risk in Asian megacities: A case study of Jakarta. Hydrological Research Letters, 12(3), 14–22. https://doi.org/10.3178/hrl.12.14

[378] https://www.jbarisk.com/flood-services/event-response/a-retrospective-view-of-floods-in-jakarta/

[379] Martinez, R., & Masron, I. N. (2020). Jakarta: A city of cities. *Cities*, *106*, 102868. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7442427/

[380] Martinez and Masron (2020)

[381] Asdak and Supian (2018)

[382] Abidin, H. Z., Andreas, H., Gumilar, I., & Wibowo, I. R. R. (2015). On correlation between urban development, land subsidence and flooding phenomena in Jakarta. *Proceedings of the International Association of Hydrological Sciences*, *370*, 15-20.

[383] Martinez and Masron, 2020

[384] Budiyono et al. (2016)

[385] https://www.britannica.com/place/Jakarta

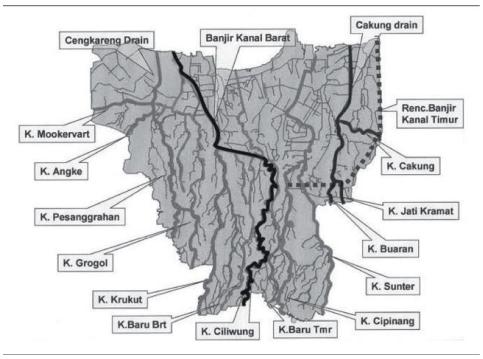
[386] Asdak and Supian (2018)

[387] Wihanesta et al., 2021. https://wri-indonesia.org/en/blog/reasons-jakarta%E2%80%99s-frequent-flooding-and-how-nature-based-solutions-nbs-can-help-reduce-risk

[388] Hurford, A. P., Maksimović, Č., & Leitao, J. P. (2010). Urban pluvial flooding in Jakarta: applying state-of-the-art technology in a data scarce environment. *Water Science and Technology*, *62*(10), 2246-2255.

is especially vulnerable[389] due to the problem of land subsidence.[390] Jakarta is the 'fastest sinking city' in the world[391], sinking 3-10cm/yr across the city, with even higher rates for northern Jakarta.[392] Around 40% of the city is already lower than the high-tide mark.[393,394] Escalating concerns about the long-term sustainability of Jakarta led to a controversial proposal to move the capital.[395,396]

Major Canals and Rivers of Jakarta



Source: Adapted from Padawangi and Douglass, 2015[397]

Socioeconomic factors: Jakarta has undergone rapid urbanization and land use change in the past decades; housing, industry, transport, and other economic assets have been created at a large scale in potentially flood-prone areas of the city.[398,399] Large-scale conversion of agricultural lands into residential and industrial areas has increasingly waterproofed surfaces (soil compaction), limiting water infiltration during floods.[400] This increases the volume of direct runoff to the city's rivers, further aggravating the risks of overflowing rivers and drainage systems. In addition, although Jakarta is naturally prone to land subsidence, excessive groundwater extraction[401] has further lowered the city's foundations.[402,403] About a third of Jakarta's population still relies on groundwater for its daily needs. Currently, groundwater extraction, especially for industrial use, is the foremost cause of land subsidence in Jakarta.[404] The lack of permeable surfaces in the city also prevents groundwater recharge.[405] This

[389] https://www.wired.co.uk/article/jakarta-sinking
[390] Shatkin, G., & Soemarwi, V. (2021). Risk and the dialectic of state informality: Property rights in flood prone Jakarta. *Annals of the American Association of Geographers*, *111*(4), 1183-1199.
[391] https://populationstat.com/indonesia/jakarta
[392] Abidin et al. (2015)
[393] Shatkin and Soemarwi (2021)
[394] Azhar, H. N., Fatima, H. H. P., & Tamas, I. N. (2020). Preliminary study of indonesia capital city relocation based on disaster mitigation principle with mental model approach. In *E3S Web of Conferences* (Vol. 148, p. 06002). EDP Sciences.
[395] The Indonesian government decided to shift the capital to a new city to be built on the island of Borneo. However, many sections of society have opposed shifting the capital, claiming that this would lead to unnecessary expenditures (at estimated costs of over $30 billion), deforestation and environmental degradation in setting up a new city with modern infrastructure. Source: https://sdg-action.org/sustainable-development-in-the-face-of-floods-and-rising-sea-levels-jakarta-case-study%EF%BF%BC/
[396] Azhar et al. (2020)
[397] Padawangi, R., & Douglass, M. (2015). Water, water everywhere: Toward participatory solutions to chronic urban flooding in Jakarta. *Pacific Affairs*, *88*(3), 517-550.
[398] Budiyono et al. (2016)
[399] Abidin et al. (2015)
[400] In the last four decades, urban land use in Jakarta has increased by 276%. Source: Garschagen, M., Surtiari, G. A. K., & Harb, M. (2018). Is Jakarta's new flood risk reduction strategy transformational?. *Sustainability*, *10*(8), 2934.
[401] https://news.detik.com/berita/d-5306804/35-warga-dki-masih-gunakan-air-tanah-pam-jaya-aspek-lingkungan-terganggu
[402] Wihanesta et al. (2021)
[403] Shatkin and Soemarwi (2021)
[404] Takagi, H., Esteban, M., Mikami, T., & Fujii, D. (2016). Projection of coastal floods in 2050 Jakarta. *Urban Climate*, *17*, 135-145. https://doi.org/10.1016/j.uclim.2016.05.003
[405] https://www.wired.co.uk/article/jakarta-sinking

has severely depleted the groundwater levels and the storage capacity of the aquifers.[406]

3.5.2 Legislative framework

This section aims to highlight some of the key aspects of the national and local regulatory framework having a bearing on Jakarta's flood management strategies and the science, technology and innovation landscape.

The government in Indonesia operates at three levels: provinces, cities, and regencies (rural local governments)[407]. Governance at each level has specific functions, with the national government as overarching entity, issuing general directions for plans and policies at the lower levels[408]. The administrative structure of DKI Jakarta [409] is unique: as the city is also an autonomous province, it has the authority to define its own policies and budget allocations.

Indonesia's relevant planning processes primarily focus on development and spatial planning, with the latter also including water management issues.[410] Most planning documents in the country explicitly include sustainable development objectives.[411] The respective governments at the various levels have to prepare socio-economic development plans according to the National Development Planning System Law (Law No. 25/2004) and spatial plans according to the Spatial Planning Act (No. 26/2007).[412] The overarching 2005-2025 Long-Term National Development Plan (RPJPN 2005-2025)[413] aims to promote the creation of a developed, self-reliant, democratic and just society with a specific focus on the promotion of agriculture, mining, manufacturing, and human resources[414]. It comprises four separate medium-term plans (RPJMNs), with a duration of five years. Currently, the fourth RPJMN (2020-2024) is underway[415], integrating the 17 Sustainable Development Goals (SDGs) and their indicators to shape the country's development agenda. Its primary focus is to promote sustainable infrastructure, human development, and better public services and welfare standards.[416]

All provinces must develop a new spatial plan every 20 years. The spatial plans at various levels of government are evaluated vis-à-vis the three dimensions (economy, environment, and society) of sustainability.[417] The Jakarta 2030 Regional Spatial Plan (Jakarta RTRW 2030), enacted in 2012[418], is an ambitious and inclusive plan focusing on rigorous

[406] Renaldi, A. (2022). Indonesia's giant capital city is sinking. Can the government's plan save it?. Environment. National Geographic. (July 29, 2022). https://www.nationalgeographic.com/environment/article/indonesias-giant-capital-city-is-sinking-can-the-governments-plan-save-it#:~:text=Jakarta%20is%20now%20sinking%20at,of%20an%20inch%20a%20year.

[407] https://www.mlit.go.jp/kokudokeikaku/international/spw/general/indonesia/index_e.html

[408] Sunarharum, T. M., Sloan, M., & Susilawati, C. (2016). Managing Jakarta's Flood Risk after Hyogo: Policy & Plan Analyses. https://www.researchgate.net/profile/Tri-Mulyani-Sunarharum/publication/344442685_Managing_Jakarta's_Flood_Risk_after_Hyogo_Policy_Plan_Analyses/links/5f75f67ca6fdcc00864cf041/Managing-Jakartas-Flood-Risk-after-Hyogo-Policy-Plan-Analyses.pdf

[409] Daerah Khusus Ibukota, or Jakarta Special Region. Source: Sunarharum et al., 2016

[410] Sunarharum et al. (2016)

[411] Drestalita, N. C., & Saputra, R. T. (2019). The Jakarta Detailed Spatial Plan evaluation based on sustainable development principles. In *IOP Conference Series: Earth and Environmental Science* (Vol. 340, No. 1, p. 012032). IOP Publishing.

[412] https://www.mlit.go.jp/kokudokeikaku/international/spw/general/indonesia/index_e.html

[413] https://policy.asiapacificenergy.org/sites/default/files/LONG-TERM%20NATIONAL%20DEVELOPMENT%20PLAN%20OF%202005-2025%20%28EN%29.pdf

[414] https://www.indonesia-investments.com/projects/government-development-plans/national-long-term-development-plan-rpjpn-2005-2025/item308

[415] https://policy.asiapacificenergy.org/sites/default/files/LONG-TERM%20NATIONAL%20DEVELOPMENT%20PLAN%20OF%202005-2025%20%28EN%29.pdf

[416] https://perpustakaan.bappenas.go.id/e-library/file_upload/koleksi/migrasi-data-publikasi/file/RP_RKP/Narasi-RPJMN-2020-2024-versi-Bahasa-Inggris.pdf

[417] Drestalita et al. (2019)

[418] Hasibuan, H. S., & Mulyani, M. (2022). Transit-Oriented Development: Towards Achieving Sustainable Transport and Urban Development in Jakarta Metropolitan, Indonesia. *Sustainability*, *14*(9), 5244.

urban planning principles such as protecting green spaces and transit-oriented development.[419] Its goal is to "create a safe, pleasant, productive, and sustainable" city. The spatial plans for the city include strategies for economic development, a sustainable environment (sustainable transport, energy management, water management, waste management, green areas, and biodiversity), and sustainable societies (sustainable housing, inclusive communities, safety, and security).[420]

Flood risk is also addressed in the National Action Plan for Disaster Risk Reduction (NAP-DRR) 2010–2012 by the National Development Planning Agency (Bappenas) and UNDP. Indonesia has initiated linking Climate Change Adaptation (CCA), DRR and flood management. In 2017, the Ministry of Environment and Forestry (KLHK) and the National Disaster Management Agency (BNPB) introduced the DRR-CCA convergence framework. This aims to build convergence between DRR and CAA in five dimensions: policy, institutions, budget, project management and methodology.[421,422] Efforts have also been taken to integrate disaster plans with development and spatial plans[423,424], for example by combining hazard and vulnerability maps to evaluate spatial plans to take decisions on land allocation.[425]

The national government also issues general directions for plans and policies framed at the lower levels for DRR.[426,427] The Indonesian government ratified a Disaster Management Law (DML) in 2007[428], drawing its approach and principles from the Hygo Framework for Action (HFA).[429] It elaborates roles and responsibilities of national and local governments and the obligations of local communities, NGOs, private sector and donor agencies. Local government bodies must follow DML norms to frame disaster management regulations and systems. The DML also aims to democratize disaster management in the country by engaging diverse actors, making the process more transparent and efficient, and developing and strengthening the country's institutional structure for disaster management.[430] Accordingly, the DML allows local agencies and actors to participate in disaster management by preparing site-specific, hazard-specific, and vulnerability-specific management systems in addition to enhancing lower-level governance capabilities[431]. It stipulates that disaster financing is the responsibility of both the national and local

[419] World Bank. (2011). JAKARTA- Urban Challenges in a Changing Climate. Mayors' Task Force on Climate Change, Disaster Risk and the Urban Poor. https://documents1.worldbank.org/curated/en/132781468039870805/pdf/650180WP0Box360ange0Jakarta0English.pdf

[420] Drestalita et al. (2019)

[421] With help from UNDP. Source: Dwirahmadi, F., Rutherford, S., Phung, D., & Chu, C. (2019). Understanding the operational concept of a flood-resilient urban community in Jakarta, Indonesia, from the perspectives of disaster risk reduction, climate change adaptation, and development agencies. *International journal of environmental research and public health*, *16*(20), 3993.

[422] The adoption of international frameworks such as the Hygo FrameworK, Sendai Framework, the SDGs, has further helped in mainstreaming DRR, CCA with development. (Dwirahmadi et al., 2019)

[423] Putra, D. I., & Matsuyuki, M. (2019). Disaster management following decentralization in Indonesia: Regulation, institutional establishment, planning, and budgeting. *Journal of Disaster Research*, *14*(1), 173-187.

[424] As an example of how international collaborations have helped, Deutche Gesselschaft fur Technische (GTZ), developed guidelines for integrating DRR criteria into spatial planning of the Yogyakarta Municipality. (Rachmawati, 2017)

[425] Sutanta, H., Rajabifard, A., & Bishop, I. D. (2010). Integrating spatial planning and disaster risk reduction at the local level in the context of spatially enabled government. *Spatially enabling society: Research, emerging trends and critical assessment*, *1*, 56-68.

[426] Sunarharum et al. (2016)

[427] The introduction of decentralisation post-1999 distributed the powers and responsibilities between the national, regional and local governments (Putra and Matsuyuki, 2019) and defined the roles of national and local governments in DRR (Djalante et al., 2017).

[428] Mardiah, A. N., Lovett, J. C., & Evanty, N. (2017). Toward integrated and inclusive disaster risk reduction in Indonesia: Review of regulatory frameworks and institutional networks. *Disaster risk reduction in Indonesia*, 57-84.

[429] HFA 2005-2015 is a global blueprint for disaster risk reduction efforts with a ten-year plan, adopted in January 2005 by 168 Member States of the United Nations at the World Conference on Disaster Reduction. Its overarching goal was to build resilience of nations and communities to disasters. The successor instrument to the HFA is the Sendai Framework, adopted in 2015.

[430] Putra and Matsuyuki (2019)

[431] Mardiah et al. (2017)

governments.[432] Local regulations must also refer to guidelines issued by the Minister of Home Affairs (MOHA) and BNPB. MOHA No. 46/2008, established a Regional Disaster Management Agency (BPBD).[433]

The national policy agenda prioritizes technology and innovation to strengthen the national system of innovation.[434] The framing of policies on science, technology, and innovation under the RPJMN (2020-2024) primarily comprises pillars 1 and 2. Pillar 1 focuses on human development and excellence in science and technology, while pillar 2 emphasizes on sustainable economic development.[435] In order to promote downstream innovation and commercialization in the priority economic sectors, the government is setting up Science and Technology Parks (STPs). The STPs are designed to promote R&D cooperation between tertiary institutions, R&D institutions, and industry, support innovation-based industry, and develop quality learning services.[436,437] It is not clear whether flood management is a focus area for the STPs.

3.5.3 The Indonesian NSI

Indonesia recognizes the significance of strengthening the elements of the national innovation system and the impacts it could have on national competitiveness.[438] However, the national innovation system is still at the initial stage of development. It comprises a network of relevant government authorities, private firms, universities, research centers, and public institutions that develop, disseminate, and deploy new knowledge and technologies[439] for three primary technology users: individuals, industry and government institutions. To promote innovation, the government mainly focuses on improving human resources, creating facilities, institutional and network support, and developing new STPs.[440]

The Ministry of Education, Culture, Research, and Technology (MOECRT) is the central government ministry responsible for managing education, cultural, research, and technology affairs within the Indonesian government.[441] The MOECRT formulates policies in science and technology and coordinates the implementation of science and technology policies in higher education institutions (HEIs).[442] The ministry was formed in 2021 by merging the Ministry of Education and Culture and the Ministry of Research and Technology (RISTEK), with the latter responsible for promoting activities in the field of research, science, and technology. RISTEK's powers and responsibilities were given to the National Research and Innovation Agency (Badan Riset dan Inovasi Nasional, or BRIN). Accordingly, in the present day, BRIN is the principal agency responsible for research and innovation in the country. Following Presidential Regulations (Perpres) 33 and 78 of 2021, different research institutes such as LIPI, BATAN, LAPAN, and BPPT[443], and research agencies operating within various ministries have been merged with BRIN, transforming it into a "super-government agency" with an "overarching" role to promote science and technology in the country.[444]

[432] Putra and Matsuyuki (2019)
[433] Putra and Matsuyuki (2019)
[434] Zhongming, Z., Linong, L., Xiaona, Y., Wangqiang, Z., & Wei, L. (2020). Innovate Indonesia: Unlocking Growth through Technological Transformation.
[435] https://www.adb.org/sites/default/files/project-documents/55063/55063-001-rrp-en.pdf
[436] https://www.adb.org/projects/55063-001/main
[437] Five higher education institutions (HEI) have been identified to set up the STPs: Bogor Agriculture University (IPB), Institute of Technology Bandung, Gajah Mada University, University of Indonesia, and Institute of Technology Sepuluh Nopember
[438] Aldianto, L., & Agustini, E. S. (2011, July). Innovation in Indonesia: The types, the necessary factors, and the national innovation system. In *2011 Proceedings of PICMET'11: Technology Management in the Energy Smart World (PICMET)* (pp. 1-10). IEEE.
[439] Zhongming et al (2020)
[440] https://www.nesta.org.uk/report/understanding-innovation-policymakers-indonesia/indonesias-innovation-system-at-a-glance/
[441] https://www.kemdikbud.go.id/main/tentang-kemdikbud/visi-dan-misi
[442] https://www.adb.org/projects/55063-001/main
[443] Respectively: the Indonesian Institute of Sciences, National Nuclear Energy Agency of Indonesia (Badan Tenaga Nuklir Nasional, National Institute of Aeronautics and Space (Lembaga Penerbangan dan Antariksa Nasional), Agency for the Assessment and Application of Technology
[444] Burhani, A. N., Mulyani, L., & Pamungkas, C. (2021). The National Research and Innovation Agency (BRIN): A new arrangement for research in Indonesia.

The R&D activities in the country are mainly supported by government funds[445] and undertaken by HEIs, government R&D agencies and private sector organizations[446]. However, several studies show that the HEIs play the most crucial role in R&D initiatives[447,448, 449] as they have the mandate to manage government and other research funding and allocate it to specific research proposals. They generally also have their own innovation units, such as STPs, to support downstream R&D development[450]. Although private firms undertake in-house R&D, universities, research institutes, and private firms have collaborated on research projects only on rare occasions.[451] While HEIs and public research institutes have access to funds, most of their R&D projects are academic in nature[452]. There are very few indigenous technologies, and their contribution to industrial development or improved social welfare is limited. Further, the spending on R&D activities both at the macro and micro levels is seen as inadequate.[453, 454]

On flood-related issues, Indonesia has a long and rich history of international collaborations to learn and draw resources from global systems of innovation. The Indonesian government and agencies mobilize both funds and technical expertise from international governments (Netherlands, Japan, Australia, etc.), agencies (World Bank, JICA, ADB, etc.)[455], and the private sector (primarily Dutch firms) to enhance the efficiency of the ongoing and proposed flood management projects in the country.[456]

3.5.4 Description of the initiatives

Indonesia is implementing a range of flood risk reduction and management strategies, both at the city and national level.[457] Jakarta's strategies can be categorised into three main types:

- Structural/infrastructural/engineering measures, e.g., construction of sea walls and embankments;
- Non-structural measures, e.g., early warning systems;
- Initiatives by community organizations, e.g., awareness building, rescue operations.

These are each described in more detail in the sections below.

3.5.4.1 Structural measures

Most planned flood management initiatives in Indonesia in general, and Jakarta in particular, have focused on structural or engineering solutions, including building sea walls, dikes, floodgates, and canals, as well as dredging and normalizing rivers.[458] Here, we focus on the National Capital Integrated Coastal Development master plan, including the Great Sea Wall Project, and the normalization and naturalisation of the local rivers.

The National Capital Integrated Coastal Development master plan and the Great Sea Wall Project

[445] Lakitan, B. (2013). Connecting all the dots: Identifying the "actor level" challenges in establishing effective innovation system in Indonesia. *Technology in society*, *35*(1), 41-54.
[446] https://www.adb.org/projects/55063-001/main
[447] Lakitan (2011)
[448] Lakitan (2013)
[449] https://www.adb.org/projects/55063-001/main
[450] https://www.adb.org/projects/55063-001/main
[451] Lakitan, B. (2011, June). National Innovation System in Indonesia: present status and challenges. In *Annual Meeting of Science and Technology Studies* (pp. 10-12).
[452] Lakitan(2013)
[453] https://www.eria.org/uploads/media/5.ERIA_Innovation_Policy_ASEAN_Chapter_4.pdf
[454] https://www.adb.org/sites/default/files/publication/575806/innovate-indonesia-unlocking-growth.pdf
[455] https://www.worldbank.org/en/country/indonesia/brief/jakarta-emergency-dredging-initiative-project-overall-project-scope-and-implementation
[456] https://www..netherlandswaterpartnership.com/news/netherlands-and-indonesia-continue-cooperation-coastal-protection-and-urban-resilience
[457] Garschagen, M., Surtiari, G. A. K., & Harb, M. (2018). Is Jakarta's new flood risk reduction strategy transformational? *Sustainability*, *10*(8), 2934.
[458] Normalization is the process of restoring the capacity of rivers, ponds, canals, etc., to their original capacity or design standards through dredging and relocating squatters from their banks. (Octavianti, 2019).

The Giant Sea Wall Project is the city's foremost 'engineering solution' for mitigating floods[459]. The initiative is part of the National Capital Integrated Coastal Development (NCICD) master plan, designed to address flooding events in the northern parts of Jakarta.[460] The basic rationale of NCICD is to close off Jakarta Bay from the sea by constructing a large sea wall.[461] The master plan for the project was developed by a Dutch consortium led by engineering and consultancy firms.[462] The project is a collaborative effort with the Indonesian government at the national level (the Ministry for Public Works and Human Settlements) and the provincial level (DKI Jakarta, Banten, and West Java), and the Dutch government (with support from the Dutch Embassy in Jakarta).

The main components of the NCICD include the construction of the sea wall in the north of Jakarta Bay, as well as large lagoons as water reservoirs along this wall to lodge the water from the 13 rivers flowing through Jakarta.[463] In addition, the NCICD has provisions for creating new land for a new city called the Great Garuda for 1.5 million people through planned seaward expansion and addressing connectivity challenges in West Java and Banten.[464] The initial project plan aimed to complete the works in 30-40 years, originally planning completion in 2025.[465] The primary technology used for the project is based on Dutch expertise on integrated water management systems. In addition to the creation of new land and the water reservoirs, it also aims to address Jakarta's challenges related to drinking water quality, sewer systems, and water pollution.[466]

The NCICD was launched after the massive floods of 2013, with project implementation planned in three phases:

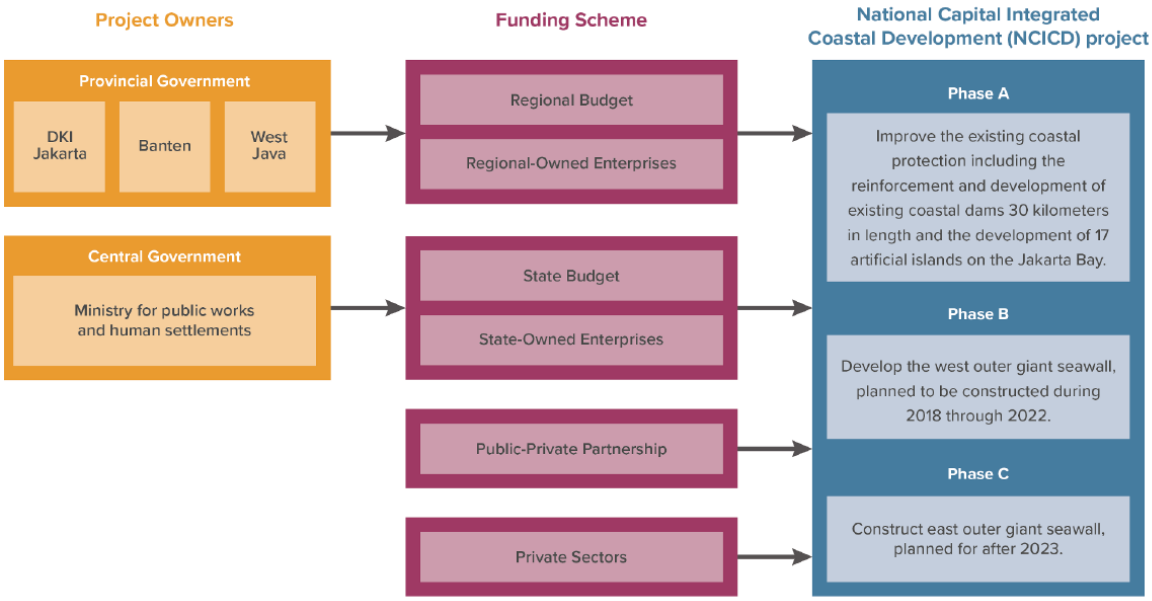
- The first phase (phase A) primarily focuses on strengthening and developing existing coastal dams and the construction of 17 artificial islands along Jakarta Bay.[467] It also includes water treatment projects to address local river pollution.[468] This phase was launched in 2014, with construction beginning in 2016.[469]
- The second phase (phase B) was aimed at constructing the West Outer Giant Sea Wall during 2018-2022[470], however, the project has been facing interruptions.[471]
- The third phase (phase C) includes the construction of the East Outer Giant Sea Wall to mitigate the problems arising out of land subsidence in the east of Jakarta Bay.[472] The last phase also includes the expansion of the port and the development of a new airport[473]. This is foreseen for after 2023.

[459] Garschagen et al. (2018)
[460] Climate Policy Initiative. (2021). Assessing Jakarta's Climate Investments. https://www.climatepolicyinitiative.org/wp-content/uploads/2021/11/Assessing-Jakartas-Climate-Investments.pdf
[461] Garschagen et al. (2018)
[462] Witteveen+Bos and Grontmij, https://www.dutchwatersector.com/news/groundbreaking-event-starts-work-on-jakartas-ambitious-40-billion-coastal-development-ncicd
[463] https://kppip.go.id/en/priority-projects/water-sanitation/national-capital-integrated-coastal-development-ncicd-phase-a/
[464] https://www.witteveenbos.com/projects/ncicd-jakarta/
[465] with an estimated investment of around USD 41.2 billion (or IDR 598.6 trillion), Climate Policy Initiative (2021)
[466] https://www.dutchwatersector.com/news/details-dutch-seawall-and-development-plan-for-jakarta-bay-well-received-by-indonesian
[467] https://kppip.go.id/en/priority-projects/water-sanitation/national-capital-integrated-coastal-development-ncicd-phase-a/
[468] https://www.dutchwatersector.com/news/groundbreaking-event-starts-work-on-jakartas-ambitious-40-billion-coastal-development-ncicd
[469] https://kppip.go.id/en/priority-projects/water-sanitation/national-capital-integrated-coastal-development-ncicd-phase-a/
[470] https://kppip.go.id/en/priority-projects/water-sanitation/national-capital-integrated-coastal-development-ncicd-phase-a/
[471] Kompas. (2019). Anies Minta "Giant Sea Wall" Dikaji Ulang. https://megapolitan.kompas.com/read/2019/01/16/16591041/anies-minta-giant-sea-wall-dikajiulang
[472] https://kppip.go.id/en/priority-projects/water-sanitation/national-capital-integrated-coastal-development-ncicd-phase-a/
[473] https://www.dutchwatersector.com/news/groundbreaking-event-starts-work-on-jakartas-ambitious-40-billion-coastal-development-ncicd

Figure 16 Three phases of the NCICD plan:A: embankment, B: sea wall west and waterfront city, C: sea wall east[474]

NCICD's ambitious plans and investments, however, have suffered substantial delays due to concerns from environmental and social groups[475] regarding a lack of required environmental and social safeguards[476], scenarios for possible socioeconomic and environmental implications, and measures to address them.[477] An argument is that the sea wall will not reduce flood impacts until 2040 unless land subsidence is controlled[478]. The NCICD recognizes that 'halting the sinking is a precondition' to save Jakarta, but the project does not include measures to address land subsidence.[479]

Figure 17 The National Capital Integrated Coastal Development Project[480]



[474] Source: Government of the Netherlands, NCICD tender document (Adapted from Bakker et al., 2017)
[475] Octavianti, T., & Charles, K. (2019). The evolution of Jakarta's flood policy over the past 400 years: The lock-in of infrastructural solutions. *Environment and Planning C: Politics and Space*, *37*(6), 1102-1125.
[476] Climate Policy Initiative (2021)
[477] Bakker, M., Kishimoto, S., & Nooy, C. (2017). Social justice at bay: The Dutch role in Jakarta's coastal defence and land reclamation. *Both ENDS*.
[478] Takagi, H., Fujii, D., Esteban, M., & Yi, X. (2017). Effectiveness and limitation of coastal dykes in Jakarta: the need for prioritizing actions against land subsidence. *Sustainability*, *9*(4), 619.
[479] Bakker et al. (2017)
[480] Based on information from the Committee for Acceleration of Priority Infrastructure Delivery (KPPIP) website (Adapted from Climate Policy Initiative, 2021)

The National Disaster Management Agency (NDMA) of Indonesia has expressed apprehensions that the project could exacerbate the flooding in Jakarta as it might slow the water flow from the drainage system to Jakarta Bay areas.[481] There is also fear for the loss of biodiversity in the coastal and mangrove areas, as well as a disturbance of the marine and coastal ecosystem, potentially leading economic losses in the fishery sector.[482,483] Some of these controversies and concerns impelled Indonesian politicians to ask the project team to redesign the initiative.[484] Accordingly, the project design was revised to have provisions for five openings in the sea bay for transport and fishing activities. If the city fails to control land subsidence by 2050, the openings will be closed.[485]

Due to intensifying concerns, the project was stalled in 2017 and was eventually suspended by the Governor of Jakarta after a re-evaluation in November 2021, which concluded that the negative impacts of the project could outweigh the benefits.[486] Reports suggest that construction activities will be completed as part of Phase A, including raising the existing coastal dam.[487] In spite of the project's suspension by Jakarta's *local* government, the *national* Ministry of Public Works and Housing is conducting a feasibility study for Phase B of the project.

Normalisation and naturalisation of the rivers and relocation of communities

The World Bank has been collaborating with the Jakarta city government since 2013 to restore flood management infrastructure (floodways, canals, retention basins) to reduce flood-related losses in the short term. This includes cooperation in the Jakarta Emergency Dredging Initiative (JEDI), also called the Jakarta Urgent Flood Management (JUFMP) project[488]. Completed in 2019, it had two main components:

- Component 1 focused on dredging and rehabilitation of selected flood infrastructure[489]. Fifteen priority segments of the floodways[490], retention ponds and canals were identified for dredging. Embankments were strengthened to increase the waterflow and prevent overtopping[491]. The project also included the rehabilitation of around 42 km of embankments/sea walls along the canals and retention basins[492].
- Component 2 focused on providing technical assistance for project implementation and management, contract management, engineering design reviews, monitoring, and supervision, social safeguards, resettlement plans, etc.

For the implementation of the project, the World Bank teamed up with key agencies in Jakarta, the Directorate-General for Water Resources (DGWR) and the Directorate-General for Human Settlements (DGCK) of the Ministry of Public Works and Jakarta. The agencies employed contractors through competitive bidding to carry out dredging

[481] Dwirahmadi, F., Rutherford, S., Phung, D., & Chu, C. (2019). Understanding the operational concept of a flood-resilient urban community in Jakarta, Indonesia, from the perspectives of disaster risk reduction, climate change adaptation, and development agencies. *International journal of environmental research and public health*, *16*(20), 3993.

[482] Dwirahmadi et al. (2019)

[483] According to a research by the Indonesian Ministry of Maritime Affairs and Fishery in September 2016, the estimated economic loss for the fishing communities in Jakarta was around tenfold, a total annual loss of Indonesian Rupiah (IDR) 137.5 billion (€ 9.4 million). (Bakker et al., 2017)

[484] PERMANASARI, E. (2019). Reading Political Insinuation In Urban Forms: Saving The Sinking Jakarta Through Giant Sea Wall Project. *Geographia Technica*, *14*.

[485] https://indonesiaexpat.id/featured/jakartas-reclamation-sea-wall-and-land-subsidence-phenomenon-continue-to-spark-debates/

[486] Kompas. (2019). Anies Minta “Giant Sea Wall” Dikaji Ulang. https://megapolitan.kompas.com/read/2019/01/16/16591041/anies-minta-giant-sea-wall-dikajiulang

[487] Climate Policy Initiative (2021)

[488] A floodways is a channel built to take the floodwaters of a river, https://floodlist.com/asia/jakarta-urgent-flood-management-project

[489] The estimated budget of component 1 was US$176.1M and the actual cost was US$111.44M. (World Bank. (2019). IMPLEMENTATION COMPLETION AND RESULTS REPORT. Report No: ICR00004907. JAKARTA URGENT FLOOD MITIGATION PROJECT (P111034). https://documents1.worldbank.org/curated/en/153081567169469254/pdf/Indonesia-Jakarta-Urgent-Flood-Mitigation-Project.pdf)

[490] The fifteen priority regions considered under the project included eleven flood floodways[490] totalling a length of 67.5 km and four retention basins covering an area of 65 hectares.

[491] https://www.worldbank.org/en/country/indonesia/brief/jakarta-emergency-dredging-initiative-project-overall-project-scope-and-implementation

[492] https://floodlist.com/asia/jakarta-urgent-flood-management-project

and rehabilitation works. The project's overall implementation was coordinated by DGWR, which hired consultants to supervise the work. In order to maintain the designed operational capacities of the flood management infrastructures, the operation and maintenance of floodways is essential. Accordingly, the concerned authorities set up drainage O&M divisions and increased funds allocated to operate and maintain them.[493]

The initiative has led to considerable improvement in water quality and an estimated reduction in flood-related losses for around 1.7 million people. The project helped revive the city's flood infrastructure, mostly built in the 1920s, having lost 75% of its water-holding capacity.[494] Also, efforts were taken to minimize the impacts of construction and rehabilitation activities on communities in the regions under component 2, with periodic consultations. In regions where the resettlement of communities was inescapable, Land Acquisition and Resettlement Actions Plans (LARAPs) were prepared in consultation with the communities affected[495]. In addition, Jakarta's capacity for flood monitoring and assessment and the planning of O&M of the flood management infrastructure was addressed.[496] Besides other benefits, the project enhanced project management capabilities of the organizations involved and strengthened coordination bet ween project implementation units at the national and provincial levels.

Figure 18 Ciliwung River after 'normalisation'[497].

3.5.4.2 Non-structural and community-centered/driven efforts

Early Warning Systems

The establishment of effective early Warning Systems (EWS) is an important non-structural measure to minimize losses from floods.[498] EWSs have been traditionally used in Indonesia in flood-prone regions. During flood season, communities living near the river take turns and serve as guards near the bank to monitor the water level and sound

[493] https://www.worldbank.org/en/country/indonesia/brief/jakarta-emergency-dredging-initiative-project-overall-project-scope-and-implementation

[494] World Bank. (2019). IMPLEMENTATION COMPLETION AND RESULTS REPORT. Report No: ICR00004907. JAKARTA URGENT FLOOD MITIGATION PROJECT (P111034). https://documents1.worldbank.org/curated/en/153081567169469254/pdf/Indonesia-Jakarta-Urgent-Flood-Mitigation-Project.pdf

[495] https://www.worldbank.org/en/country/indonesia/brief/jakarta-emergency-dredging-initiative-project-overall-project-scope-and-implementation

[496] In 2012, a Flood Management Information System (FMIS) was established with a grant of US$0.5M from the Netherlands.

[497] Bukit Duri. Napier, J. (2021). Living with Water: Infrastructure and Urbanism in Jakarta. Ecocycles, 7(1), 52-72. See: http://real.mtak.hu/129385/1/NAPIER_GALLEY.pdf

[498] Budiyono, Y., Wijayanti, P., Siswanto, S., Aerts, J. C., & Ward, P. J. (2017). Flood risk decrease resulting from Flood Early Warning System in Jakarta. https://www.researchgate.net/profile/Yus-Budiyono-/publication/350353818_Flood_risk_decrease_resulting_from_Flood_Early_Warning_System_in_Jakarta/links/605b4a03a6fdccbfea047666/Flood-risk-decrease-resulting-from-Flood-Early-Warning-System-in-Jakarta.pdf

the alarm to nearby inhabitants using a traditional instrument when needed.[499] Currently, EWSs in Jakarta operate through TV and radio news, mobile phone text messages, water level sirens, warning messenger bicycles with speakers, flood information boards, etc.[500]

The Jakarta Regional Disaster Management Agency (BPBD) has introduced many early warning devices for the onset of floods and related weather conditions.[501] The city of Jakarta owns three categories of early warning devices. These include Disaster Warning Systems (DWS), Automatic Weather Systems (AWS) or weather gauges, and Automatic Water Level Recorders (AWLR), used to measure water levels. DWS primarily focuses on people living on the riverbanks and alerts communities when the water level nears the danger mark.[502]

Along with government authorities, several NGOs are also implementing EWS.[503] In addition, international agencies and other countries have collaborated with the Indonesian authorities and local communities to build the resilience of vulnerable populations. For instance, the Australian government and the Australian chapter of children's right NGO Plan International have collaborated with Plan Indonesia to work on community resilience since 2015.[504] Plan Indonesia engages local partners, youth and communities to conduct disaster mapping and study socio-economic and psychological implications of disasters such as floods. The capacity building initiatives of Plan Indonesia also include the development of early warning tools using locally available materials (plastic pipes, loudspeakers, cables, etc.). Plan Indonesia and its local partners have also collaborated with the Agency for the Assessment and Application of Technology (BPPT) to augment the performance and maintenance of the EWS.

Besides helping people evacuate flood-affected areas and building resilience, this initiative has promoted local innovation and engaged the local communities and youth to come up with a 'simple and inclusive device'. Moreover, because the residents are involved in the installation and operation of the EWS, they do not panic when the alarm sounds and know what needs to be done[505]. The partnership also showed that resources, knowledge, and capacities of the local communities and youth could be tapped into and enhanced to make disaster risk reduction more inclusive and participatory.[506]

Flood control system using the Internet of Things (IoT) and artificial intelligence (AI)

In order to replace traditional manual flood monitoring and control systems and enhance the efficiency of its flood management systems, Jakarta Smart City[507], in collaboration with the Jakarta Water Resource Service (DSDA), has developed a flood control system that is based on the Internet of Things (IoT) and artificial intelligence (AI). The new system helps predict potential floods and optimizes flood management activities during a flood, besides raising general awareness, facilitating government actions, and providing real-time flood monitoring data.[508] Various kinds of sensors, such as those measuring rainfall, waterflow, water level, temperature and vibrations, have been installed at various critical locations. The data received from the sensors are integrated into one platform, along with historical data. They are then assessed and analysed to generate information on weather conditions, the likelihood of floods, potential solutions for managing the floods, etc. The monitoring and flood prediction data help the government

[499] The kentongan (wooden or bamboo gong) .Budiyono et al., 2017

[500] Byicycles with speakers spreading warning messages, Lassa, J. A., Sagala, S., & Suryadini, A. (2013). Conceptualizing an established network of a community based flood early warning system: Case of Cawang, East Jakarta, Jakarta. Working Paper No. 3. http://www.irgsc.org/pubs/wp.html

[501] https://www.preventionweb.net/files/72308_floodearlywarningsystemdevelopment.pdf

[502] https://news.detik.com/berita/d-4857857/begini-cara-bpbd-dki-sebar-peringatan-dini-banjir-ke-warga

[503] e.g., World Vision Indonesia, WVI . Source: Lassa et al., 2013

[504] https://www.preventionweb.net/files/72308_floodearlywarningsystemdevelopment.pdf

[505] The implementation of the EWS is not free from challenges. Since most of the disaster management budget is directed toward the creation of physical infrastructures, installation of EWS and building of community resilience is left with very limited investments. EWSs are only effective when the communities trust the alarms or the warnings.

[506] https://www.preventionweb.net/files/72308_floodearlywarningsystemdevelopment.pdf

[507] Jakarta is trying to become a smart city by 2025 through implementing Information and Communication Technology (ICT) to monitor, analyse and manage the city's resources and maximize public services, providing solutions, and support sustainable development. The Jakarta Smart City (JSC) project was started in 2014.

[508] https://www.aseanwater.net/wp-content/uploads/2022/08/Flash-Flood-System-in-Indonesia-1-2.pdf

make data-based decisions and optimize response mechanisms during floods. In the long term, installing these IoT sensors will generate data time series, making flood prediction and monitoring more precise and scientific. This will in turn enhance the efficiency and impact of government policies and actions.[509] This innovation has been awarded ITU World Summit on the Information Society Forum 2022 prizes for e-Science and an IDC Smart City Asia Pacific Award 2022 for Public Safety.[510]

3.5.5 Assessment of the initiatives

This section aims to understand how the flood management strategies in Jakarta have contributed to the establishment of systemic innovation functions and strengthened Indonesia's NSI.

Knowledge development and diffusion: Indonesia has tapped into the global innovation system, as well as international expertise and resources to devise and implement flood management strategies. Several collaborative projects and initiatives have been/are being undertaken with bilateral or multilateral experts and donor agencies. In its efforts to manage floods, Jakarta has been generating a diverse and considerable amount of data and knowledge[511], mostly in collaboration with international partners. Noteworthily, for each project, efforts have been made to create specific networks of actors[512] or mini-innovation systems. Each time, this has led to new knowledge and skill development. In addition, the government also undertakes studies and surveys to assess the causes of disasters and the impacts of DRR mechanisms put in place, crediting increased awareness and preparedness among flood-prone communities.[513]

This knowledge generation has led to the identification of effective strategies for better risk management, such as use of forecasting tools, EWS, community awareness, etc. The knowledge generated has also been continuously shared with relevant stakeholders, including local communities, as part of capacity building and awareness-raising initiatives. The country has also augmented its institutional and technological capacity by setting up organizations and systems to provide early flood hazard warnings. Moreover, the institutions have graduated from only focusing on the material impacts to considering how people's lives are impacted socially, particularly social conflicts and challenges faced by displaced communities. However, the country still needs to develop and strengthen a 'culture of safety, preparedness, and resilience' by further improving risk knowledge, training, and preparedness drills at the local level focusing on the vulnerable communities.[514]

Entrepreneurial experimentation: Much entrepreneurial foresight and pragmatism have been employed to design flood management project structures and implementation. For instance, in the Giant Sea Wall project, different private firms (local and international) were responsible for different components/parts of the project. This resulted in transparent procedures, making the processes easier to regulate. In addition, multiple funding sources were utilised to generate resources for large projects involving large investments.[515] This helped generate the scale of funds required and distributed risks and ownership among actors. Furthermore, within the project consortia, partners have specific roles and contributions. For instance, in the Giant Sea Wall project, funding was sourced from the Dutch government, the technical expertise from Dutch firms, and the World Bank carried out modelling and scientific assessments. On the Indonesian side, national and provincial government agencies provided legislative backing and operational structure to the overall project and local contractors were engaged in the execution of the project. The Giant Sea Wall construction project design had provisions for developing shopping malls, skyscrapers, luxury flats, and similar attractions to allure private investment in the initiative.

[509] Sensor Flood Control. (2022). Smartcity. https://smartcity.jakarta.go.id/id/blog/mengintip-sensor-flood-control-system/
[510] Flood Control System Jakarta Menang Ajang Bergengsi Tingkat Dunia WSIS Prizes 2022. (2022). beritajakarta.id.
[511] For instance, hydraulic modeling, flood hazard mapping (to predict floods and study the impacts and losses), assessment of flood-related infrastructures, spatial zoning studies, land subsidence analysis, assessment of contingency plans, etc.
[512] Funders, technology providers, project implementors, interfaces between the communities and the markets, coordinators between institutions and agencies, etc.
[513] Djalante, R., Garschagen, M., Thomalla, F., & Shaw, R. (2017). Introduction: Disaster risk reduction in Indonesia: Progress, challenges, and issues. *Disaster risk reduction in Indonesia*, 1-17.
[514] Djalante et al. (2017)
[515] E.g funds from the Dutch, Australian, Japanese, and Indonesian governments as well as private sector funds from different countries.

Market formation: Market creation has not been an explicit objective of the initiatives. However, efforts have been made to create market opportunities through private sector participation in the implementation of flood management activities, including through private investments and competitive tendering procedures.

Resource mobilisation: Most of Jakarta's flood management initiatives are being undertaken as collaborative initiatives in partnership with national and international actors as joint projects or public-private partnerships. International partners (including international private sector actors) help provide/ mobilise funds and technical know-how which are limiting factors in Indonesia. Nonetheless, central and provincial governments have also invested in the projects. Funds coming from international sources are in the form of loans, investments by foreign firms, development assistance, etc. For the NCICD project, the huge financial requirements made private sector investment indispensable, resulting in the creation of public-private partnership models. However, inadequate funds allocated to O&M of flood infrastructure by the responsible ministries at the central and provincial levels resulted in sub-optimal performance.[516] Funds could also be used more efficiently to ensure the completion of projects. Nonetheless, the government employs an entrepreneurial outlook in project planning and implementation and engages in the projects as a trusted investment partner.

Influence on the direction of search: Given that recurrent floods are a significant policy and socioeconomic challenge, and an elaborate legislative framework is in place, the primary driver of research and innovation is flood-related legislation in the country. The direction of the search is also influenced by the involvement of international partners with specific knowledge, skills, and perceptions on how to deal with urban floods and their interactions with local actors. The potential massive and long-term impacts on the lives and livelihoods of the natives, especially vulnerable communities, also impacts the ongoing research in the country, directly and indirectly. For instance, the impacts of floods on people's daily lives trigger innovation both at informal (e.g., local people) and formal levels (universities, R&D institutes) to devise solutions to help communities respond better to flood-related challenges and recover faster from losses incurred.

Legitimation: The country's elaborate legislative framework drives and regulates Jakarta's flood management activities. In addition, government, donor agencies, and other international partners undertake serious efforts to create awareness among, and acceptance by, local communities of their activities. Government agencies conduct technical consultations, road shows, input sessions and focus group discussions with local communities and other relevant stakeholders to enhance credibility and public participation. For instance, public input on the framing of the spatial plan for Jakarta was sought for three months, using both traditional methods of stakeholder consultations and a dedicated website created to publicize the plan's draft and solicit suggestions from the public.[517] However, the extent to which public opinion was actually considered, hence the effectiveness of the stakeholder consultations, is debated.[518] This has also turned out to be a challenge for the Great Sea Wall project.

Capacity-building and awareness-raising programmes being undertaken by the Indonesian agencies also, directly and indirectly, generate credibility for the government's flood management activities. Such programmes inform communities about government projects and enhance communities' adaptive capacity and preparedness, making it easier to implement projects, with less resistance from the locals. In many cases, when the authorities anticipate social tension or unwillingness by the local actors to participate, non-state actors such as NGOs, local leaders, and capacity-building organizations are roped in to act as an interface between the government and the locals. The creation of economic opportunities and benefits such as shopping malls and new housing also contributes to the legitimation of flood management projects.

Development of positive externalities: The various awareness-raising, community preparedness programmes, capacity building of institutions, government agencies, and private sector firms have several co-benefits over and above better management of floods in the city. Interactions between different stakeholder groups has led to

[516] World Bank (2019)
[517] http://indonesiaurbanstudies.blogspot.com/2010/02/the-flawed-planning-process-of-2030.html
[518] World Bank (2011)

stronger networks for innovation. Infrastructure development for flood management has helped in better water management systems, cleaner rivers and drinking water, etc.
The table below presents the summarized findings of the structure-function coupled analysis of Jakarta's flood management initiatives.

3.5.6 Role in NDCs

The programmes and strategies outlined in the Indonesian NDC to the UNFCCC have elaborate adaptation goals that include flood risk management. Some of the adaptation strategies listed directly affect flood management[519], such as sustainable agriculture, integrated watershed management, reduction of forest deforestation and degradation, land conversion. Some of the social and livelihood resilience strategies that have a bearing on mitigating flood risks include the enhancement of adaptive capacities, community capacity development, participation in local planning processes, disaster preparedness programmes, identification of highly vulnerable areas, etc. Primary ecosystem resilience measures with flood hazard management aspects include coastal protection, ecosystem restoration, etc.

Almost all strategies listed in the NDC are an integral part of Jakarta's overall flood management strategy. Keeping in view the country's NDC, the Jakarta government is trying to minimize the risks and impacts on all development sectors by building actor capacities, knowledge generation, management, policy implementation, etc.[520] Some measures, such as mangroves development, and integrated water management, contribute to both the adaptation and mitigation components of the NDC[521]. Thus, Jakarta's efforts to manage floods positively contributes to the country's objectives stated in its NDC.

[519] MoEF. (2021). Updated Nationally Determined Contribution Republic of Indonesia. https://unfccc.int/sites/default/files/NDC/2022-06/Updated%20NDC%20Indonesia%202021%20-%20corrected%20version.pdf
[520] https://unhabitat.org/sites/default/files/2020/06/ndc_guide_19062020.pdf
[521] Basuki, T.M.; Nugroho, H.Y.S.H.; Indrajaya, Y.; Pramono, I.B.; Nugroho, N.P.; Supangat, A.B.; Indrawati, D.R.; Savitri, E.; Wahyuningrum, N.; Purwanto; et al. Improvement of Integrated Watershed Management in Indonesia for Mitigation and Adaptation to Climate Change: A Review. Sustainability 2022, 14, 9997. https:// doi.org/10.3390/su14169997

Table 11 Structure-function-coupled analysis of Jakarta's initiatives

F	Function	Structural element	Jakarta's interventions
F1	Knowledge development and diffusion	Actors	• Studies/surveys undertaken by the Indonesian agencies, independently and in collaboration with international organizations, have generated large amount of knowledge and skills related to flood management • Capacity building, awareness-raising, and diffusion of knowledge related to flood management have created relatively more informed, aware, and capable communities (e.g., enhanced forecasting of floods by local people, communities know what needs to be done before/during/after floods) • The urgency to manage floods has also led to local innovations and adaptive mechanisms (EWS, coping systems during floods such as storage of food, water, etc.) • NGOs, local bodies also promote local innovations
		Institutions	• Policy and programme implementation, and surveys and studies undertaken by the institutes enhanced their know-how and skills
		Interactions	• Interactions with international partners led to significant learning regarding institutional development, project management, coordination, monitoring of progress, evaluation of outcomes, etc. • Multi-level governance led to enhanced capability to collaborate between organizations
		Infrastructure	• Both public and private sector in Jakarta enhanced their skills and know-how on infrastructure development
F2	Entrepreneurial experimentation	Actors	• The project consortia were formed based on the type of resources and skills required for the project implementation • Investment-intensive, long-term projects were modeled on public-private partnerships • Each partner/actor had a specific role in the project
		Institutions	• Public sector participation in projects ensured legislative support and addressed risks to investment by the private sector
		Interactions	• Investment intensive projects engaged private sector actors
		Infrastructure	•
F3	Market formation	Actors	•
		Institutions	• Government and authorities participated in the projects, amongst others, to create an investment-friendly setting and using competitive procurement procedures
		Interactions	• Project partnerships and interactions with international project partners created business opportunities for the local industry, firms, contractors, etc.
		Infrastructure	• Some of the infrastructure projects also focused on market formation through competitive tendering for flood management activities • Jakarta Smart City and Jakarta Water Resource Service (DSDA) developed a flood control system based on IoT, AI
F4	Influence on the direction of search	Actors	• Funding agencies, international project partners, etc. guide the search • Local communities also came up with innovative solutions for managing flood impacts • NGOs also engage in local innovation projects
		Institutions	• Legislation and policies are the primary determinant for institutional R&D and innovation in the city/country

		Interactions	• Interactive learning with project partners also influenced the search
		Infrastructure	• The need for the construction of new infrastructure and tfor improvements in existing infrastructure also guided the initiatives
F5	Resource mobilization	Actors	• Government and its agencies mobilized funds and technological support from the project partners (including international agencies and governments, private sector firms, etc.) • International firms provided large scale funding, making projects financially viable and helping leverage funding from other sources
		Institutions	•
		Interactions	• Interactions with potential funders and technology/knowledge providers helped mobilize resources
		Infrastructure	•
F6	Legitimation	Actors	• Capacity and awareness building, consultations, FGDs, negotiations, etc., with stakeholders were undertaken to create credibility and acceptance of the activities
		Institutions	• Institutions play a primary role in generating credibility for government actions
		Interactions	• Interactions with local communities to understand their needs/challenges/recommendations on addressing floods are aimed at building trust and confidence.
		Infrastructure	• The Sea Wall project had provisions for the development of residential estates, malls, etc.
F7	Development of positive externalities	Actors	• Development of more aware and capable stakeholders • Plan Indonesia explicitly address youth to strengthen community resilience
		Institutions	• Institutions involved develop greater capabilities, learnings and experiences from flood management activities spill over in their other engagements
		Interactions	• Interactions with international and local partners lead to more business and employment opportunities for the latter • New technologies, best practices employed
		Infrastructure	• New infrastructure, better canal, drainage, and water management systems created in the process positively impact the city's water management, pollution abatement, health impacts, aesthetic gains, etc. • The Sea Wall project had provisions for the creation of new land and the development of residential estates, malls, etc. which enhanced the investment attractiveness of the projects

3.5.7 Key success factors and lessons learned

While Jakarta's flood management experience shows both strengths and weaknesses, one feature that stands out is that the various levels of government have made significant efforts to develop a robust policy framework to address flood risks. However, since the decentralization of governance in the country, public-led groups have become aware of their rights to question the government-driven planning processes. Consequently, one of the possible explanations for observed implementation gaps and, at times sub-optimal outcomes, is that public opinion and government planning are not yet in sync[522]. Some of the critical factors that can be learned from Jakarta's experience are described below.

Integrated and collaborative governance is crucial: Flood prevention and control is a complex issue involving several interconnected actors and disciplines operating at multiple levels of society[523]. Consequently, the role of government becomes crucial to bring together divergent, multi-level stakeholders and build synergies between different perspectives[524]. The Indonesian government recognizes this and is taking steps to create synergies among actors and governance levels through stakeholder interactions and adaptive policy making. Flood management in the country is transitioning towards a more 'adaptive and integrated system.[525] Authorities realize that one of the most effective strategies to avoid ambiguities, delays, and project failures is to devise 'integrated projects', collaborating with policymakers, experts, and communities throughout planning and implementation. Such an approach can also compensate for some resource deficits and make policies more effective in the long term.[526] However, the government needs to improve collaboration and coordination between agencies and authorities to enhance the effectiveness of flood governance.[527] Furthermore, although Indonesia is already decentralizing flood governance in the country, the capacities and resources available to the local agencies must be boosted. This is because the local authorities best understand the local contexts and vulnerabilities and are the first to respond to local events.

Complex problems require a portfolio of strategies: Jakarta's situation makes it evident that complex problems such as urban floods cannot be solved through single magic bullet strategies. Managing flood-related challenges, especially in a developing country context, requires an assortment of measures. Accordingly, Jakarta's response mechanism to manage floods includes the construction of sea walls, river dredging, water management, community preparedness projects, capacity building, etc., operating at different levels, targeting different parts of the problem, while keeping in view different time scales for optimal results. Furthermore, agencies are trying to strike a balance between technical measures and socio-cultural strategies, along with measures to enhance the preparedness for recovering from flood impacts. Furthermore, in addition to planning for extreme flooding events, agencies are also trying to focus on the 'everyday problems' and structural issues (e.g., land subsidence, excessive groundwater extraction, regular flooding of roads, residential areas, insufficient clean water resources), which could be underlying, root causes of extreme flooding events. Although there is a need for more urgent and comprehensive action by the authorities to be able to avert severe losses, there is a recognition of the merits of keeping in mind the bigger picture and using major disasters as a learning opportunity to assess underlying causes, impacts, and potential solutions.

Role of future risk assessment and long-term planning is vital: Two crucial lessons can be drawn from Jakarta's experience. First, the planning processes must be thoroughly synchronized with projections, scenarios, and granular-level information available on socio-economic and environmental trends for the present and future, so as to minimize the impacts and efficiently utilize the resources. This is even more so in light of recent advancements and precision in climate science and the various socio-economic modelling exercises. The development of urban centers and infrastructures are self-propagating processes and often lead to lock-ins and path dependencies. The choices in the investments made and the design (concerning buildings, mobility, waste management, water management, etc.) of modern cities predominantly define the vulnerabilities and resilience of these places in the future. So to avoid unmanageable situations where available technologies, knowledge and

[522] Silver, C. (2014). Spatial planning for sustainable development: An action planning approach for Jakarta. *Jurnal Perencanaan Wilayah dan Kota*, *25*(2), 115-125.
[523] Wicaksono, A., & Herdiansyah, H. (2019). The impact analysis of flood disaster in DKI jakarta: prevention and control perspective. In *Journal of Physics: Conference Series* (Vol. 1339, No. 1, p. 012092). IOP Publishing.
[524] Wicaksono and Herdiansyah, (2019)
[525] Wicaksono and Herdiansyah (2019)
[526] Silver (2014)
[527] Dwirahmadi et al. (2019)

adaptation measures seem inadequate and ineffective in addressing the challenges, it becomes vital that development planning is based on future risk assessments.
Second, the actors involved in planning and implementing flood mitigation and adaptation strategies must have a flexible, adaptive outlook and consistently build and upgrade their knowledge, skills, resources, etc. Learning could be based on past experiences (successes or failures), evolving vulnerabilities, evolving knowledge domains[528] and the acknowledgment of the kinds of capabilities required to address flood-related challenges. Those in charge of planning and implementing strategies need to be convinced that there could be several solutions to one problem, and iterations, retractions, and adjustments are sometimes necessary and pragmatic.

Convergence of DRR, CCA, and development processes is crucial: There is significant overlap and complementarity between DRR, CCA, and development in terms of expertise and policy goals, particularly in the context of flood risk management.[529] Integrating them avoids duplication of expenditures and the implementation of disconnected policies and institutional conflicts.[530] Recognizing the value of inclusive and integrated management of issues, Indonesia has launched the DRR-CCA convergence framework and is trying to synchronize urban planning with the development processes. The underlying idea behind these activities is to build synergies across the domains with respect to policy, institutions, budget, project management, and methodology. However, the process of building convergence is quite complicated as collaborations have to be developed across sectors, actors, and levels of governance.[531] The problem is particularly challenging at the level of the local governments.[532]

Community preparedness and engagement of the local communities goes a long way: Communities that are aware, informed, and alert about flood risks are more prepared and capable of responding to the flood risks. Recognising this, of late, the Jakartan authorities are making serious efforts to enhance community preparedness and awareness. Government agencies, at times in collaboration with NGOs, are helping vulnerable communities to develop the ability to learn from previous floods, take early action, and project future floods. For instance, agencies are engaged in raising awareness about flood forecasting, EWS, and safe evacuation methods. Awareness campaigns are being run to influence community behaviour on waste disposal[533] and water quality management. Local communities are also being engaged in developing and implementing customized EWS, which besides leading to local innovation and capacity building, is also helping to create trust and ownership among the natives.

Context specificity of knowledge has implications for knowledge and technology-transfer outcomes: Indonesia has a long history of collaborating with the Dutch government and the private sector in flood mitigation projects. Dutch cities'[534] flood management strategies have influenced Indonesia's flood management and city planning models. However, even though there is much for Jakarta to learn from the Netherlands concerning flood management, it must be noted that the two places are very different climatically, socio-economically, and demographically[535]. They are contextually dissimilar and on different levels and stages with respect to their adaptation strategies and coping mechanisms[536]. Some experts argue that "attempts at replicating the Dutch flood management system" (which, too, has evolved over time) do not suit Jakarta's geography. Therefore, the impacts of knowledge exchange can only be maximized when it happens appropriately, keeping in mind the local context.

3.5.8 Good practices for potential replication

Based on the above lessons learned from the Jakarta experience, the following good practices can be identified that could lend themselves for replication in other countries:

[528] Including the development of new solutions, technologies, processes, methods
[529] Dwirahmadi et al. (2019)
[530] Mardiah et al. (2017)
[531] Dwirahmadi et al. (2019)
[532] Putra and Matsuyuki (2019)
[533] e.g., to address the issue of dumping of solid wastes into the river leading to its decreased water holding capacity
[534] Such as Rotterdam and Amsterdam
[535] Al Skaff, S. (2022). Resilience Through Public Spaces:"Transforming Vulnerability into Opportunity". In *Innovations in Green Urbanization and Alternative Renewable Energy* (pp. 67-76). Springer, Cham.
[536] Aerts, J., Major, D. C., Bowman, M. J., Dircke, P., & Aris Marfai, M. (2009). Connecting delta cities: coastal cities, flood risk management and adaptation to climate change.

- *Adopt a programmatic and portfolio approach to design and implement flood (and borader disaster) management strategies:* Management of urban floods (and, more broadly, natural and climatic disasters) requires action at different levels across diverse actors and sectors with different vulnerabilities and coping capabilities. There is no single magic bullet to address this complexity effectively. It requires a comprehensive policy vision buttressed by a portfolio of strategies, including abatement of impacts, adaptation mechanisms, community preparedness, new knowledge generation, science and technology innovations, networks and partnership building, resource generation, etc. The varied strategies could be implemented as programmatic projects guided by an umbrella policy goal and local development priorities.
- *Design and develop adaptive governance structures:* Adopting a flexible and adaptive governance approach is crucial to address challenges such as floods and other environmental disasters because both causes and vulnerabilities are evolving. It is vital to adopt a collaborative, adaptive approach, considering emerging knowledge, data, experience, incentive mechanisms, power structures, community needs, and institutional designs, rather than relying on top-down, fixed structures.
- *Use long-term planning using projections of socioeconomic developments and future risks:* Since the causes of environmental challenges and the factors determining their impacts evolve over time, it is crucial that long-term flood (and broader) disaster management strategies are based on purposeful combinations of long-term projections of demographic and socio-economic developments, local risk and vulnerability assessments, climate change predictions and other significant drivers of the disaster in question.
- *Participatory governance and engaging the local communities is a must:* Jakarta's experience clearly shows that participatory governance, decentralization of roles and responsibilities across agencies, and community-based coping strategies are essential for effective disaster management. A combination of top-down with bottom-up approaches will lead to strategic processes and enhanced stakeholder engagement. In addition, concerted efforts towards building the capacities of all potential stakeholders (ranging from relevant institutions to local communities) and considering their diverse perspectives in the planning and implementation processes make the exercise collaborative and increase ownership by the engaged actors. Tapping into their respective capabilities also makes the process more resource-efficient and productive (e.g., development of local EWS, etc.).
- *Integrate DRR, CCA, and SDGs for holistic gains and efficient governance:* Environmental challenges and natural disasters have significant overlaps with development processes. Moreover, DRR and CCA are complex and resource-consuming processes, so it is logical and efficient to integrate DRR and CCA with long-term development planning, including sustainable development. Integrating DRR and CCA into development agendas also helps address the underlying causes of the environmental challenges and abate community vulnerabilities. The synergies between DRR, CCA, and development can be created by integrating specific strategies, collaboration across actors, capacity building, and innovation.
- *Build networks and partnerships depending on competencies and resources required:* Different disaster management strategies need different skills, resources, and governance tools to engage and target different actors. Therefore, it is crucial that relevant networks are created for each strategy, bringing in the right kind of actor groups, capabilities, funding mechanisms, policy frameworks, and governance structures. Partnerships could be designed keeping in mind projects' specific needs (e.g., private actors can be brought in to meet the investment requirements and sharing of risks). Resources and capabilities can be sourced from local, national, and international innovation systems.

3.6 CASE: WIND ENERGY IN DENMARK

Country	Denmark	**Focus**	Mitigation
Scope	Renewable energy	**Key innovation system functions**	F1 Knowledge development and diffusion F2 Entrepre-neurial experi-mentation F3 Market formation F4 Guidance of the search F5 Resource mobilization F6 Legitimation F7 Development of positive externalities
Approach	Bottom-up and Top-down	**Starting year**	1890s - to date: local experimentation 1970s - to date: government interventions

3.6.1 Introduction to the initiative

Denmark is considered a frontrunner in wind energy.[537] With one of the world's highest amounts of wind energy generated per capita[538], 48% of the domestic electricity supply in 2020 was met by wind-generated electricity, the highest share in the world.[539]

Denmark has developed a leading wind energy innovation ecosystem, from innovation to manufacturing and deployment[540]. The Danish wind TIS comprises the world's top manufacturing and export firms, accounting for approximately 2.5% of the country's private sector jobs.[541] This success is a result of an interaction of proactive government policy support and bottom-up initiatives which together promoted innovation and experience-based learning.[542,543] These efforts allowed the country to build core competencies required in the production, design and installation of wind turbines[544] and, more recently, in turbine decommissioning and recycling.[545]

The history of the Danish wind energy industry dates back to 1891, when the first wind turbine was built as a solution for energy access and rural development. Grass-roots experimentation played a major role in innovation, as entrepreneurs and firms in rural Denmark became key actors in promoting early knowledge development via learning-by-doing.[546]

In the 1970s, after the oil crisis, the development of wind energy was systematically integrated in national energy planning as a solution for reducing energy dependency. As environmental concerns increased in the 1990s, wind energy became even more important in Danish central energy planning as the preferred means for driving emission reduction while promoting energy security, local participation and economic development.[547]

[537] IRENA-GWEC (2013) 30 Years of policies for wind energy Lessons from 12 Wind Energy Markets: Denmark. Available at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/GWEC_WindReport_All_web-display.pdf
[538] Johansen, K. (2021). Wind energy in Denmark: a short history. ieee power & energy magazine. May/June 2021, pp94-102
[539] IEA Wind TCP (2022) Wind Energy in Denmark. Available at https://iea-wind.org/about-iea-wind-tcp/members/denmark/
[540] Including also e.g. material design, as well as wind energy-related analysis and services, e.g. related to engineering, stakeholder engagement, financing, construction and operation, grid integration and energy storage, etc. See e.g.: https://winddenmark.dk/sites/windpower.org/files/media/document/Profile_of_the_Danish_Wind_Industry.pdf, https://orbit.dtu.dk/en/projects/danish-centre-for-composites-structures-and-materials-for-wind-tu ,
[541] Johansen, K. (2021)
[542] Wieczorek et al. (2015) Broadening the national focus in technological innovation system analysis: The case of offshore wind. Environmental Innovation and Societal Transitions 14 (2015) 128–148 http://dx.doi.org/10.1016/j.eist.2014.09.001
[543] Johansen (2021)
[544] Wieczorek et al. (2015)
[545] See e.g. https://www.siemensgamesa.com/newsroom/2021/01/210125-siemens-gamsa-press-release-decomblades-launched, https://stateofgreen.com/en/news/oldies-but-goldies-recycling-wind-turbines-for-new-use/
[546] Johansen (2021)
[547] IRENA- GWEC (2013)

This case summarizes the two main channels for development of the wind energy sector in Denmark, i.e. top-down government policy support and bottom-up grass-root experimentation. Then, it will assess how the combination of these two routes has contributed to the formation of one of the leading wind energy innovation systems in the world, while identifying success factors and lessons learned for potential replication.

3.6.2 Legislative framework

The legislative framework for the Danish wind innovation system was developed over decades through the establishment of several national energy plans. These plans established policies, taxes and other incentives, removed legislative barriers[548] and created the main national authorities and governing agencies that shaped the current Technology Innovation System (TIS).

Denmark is considered a pioneer in the introduction of policies and regulations to incentivize wind energy. Already in the late 1970s an energy tax was established. Tax revenues were then allocated to finance energy R&D, being one of the main funding sources for wind R&D at the time. Environmental taxes introduced in the 1980s further contributed to supporting the development of renewable energy technologies, including wind energy. The country was also one of the first countries to introduce large subsidies for its nascent wind industry and to provide regulations for local energy cooperatives, collectives of wind energy producers from local communities, to sell their electricity back to the grid. Its feed-in-tariff (FiT) system was later replicated in other countries. Moreover, Denmark created a framework for financing the development of wind energy based on a Public Service Obligation (PSO), which established taxes on energy consumers to finance the subsidies and grants provided to wind energy. [549,550,551]

The Danish Ministry of Energy (MoE) was first established in the late 1970s and was responsible for, among others, energy planning and coordinating the country's energy R&D efforts. The Danish Energy Agency (DEA), an agency under MoE[552], is responsible for tasks regarding energy production, supply and consumption. They are the regulatory authority for the electricity grid and establish the supply obligations. and are also responsible organizing the Danish energy transition on behalf of the government and coordinating Denmark's national GHG emission reduction efforts.[553] DEA also offers expertise to other countries, in association with other technical institutions in Denmark.[554]

In addition to the above, international agreements, such as the Kyoto Protocol and the Paris Agreement have influenced the formulation of national targets for renewable energy, by helping to put environmental goals higher on the agenda and helping to mobilise public support to renewable energy.[555]

3.6.3 The Danish NSI

Denmark has a highly developed national innovation system. Danish knowledge institutes lead international rankings in terms of the number of publications on wind energy.[556] Danish knowledge institutes like the Risø National Lab for Sustainable Energy[557] as well as the Aalborg University and Technical University Denmark (DTU) have been considered leading organizations in the field globally. [558] These three institutes offer polytechnic

[548] E.g. allowing the participation of independent power producers and their ability to deliver power to grid.
[549] IRENA-GWEC (2013)
[550] Wieczorek (2015)
[551] Johansen (2021)
[552] Currently the Ministry of Climate, Energy & Utilities (in Danish: KEFM)
[553] Energy-related as well as non-energy-related emissions. See: https://ens.dk/en/about-us/about-danish-energy-agency, see: https://iea-wind.org/
[554] https://um.dk/en/-/media/websites/umen/danida/results/evaluation-of-development-assistance/evaluation-programmes/2021mitigationannexs.ashx
[555] Johansen (2021)
[556] Wieczorek et al (2015)
[557] Risø National Laboratory for Sustainable Energy is a scientific research organization, founded in 1956, which became an institute of the Technical University of Denmark (DTU) in 2008. It was dissolved in 2012, and its location is now known as the DTU Risø Campus, home to a number of institutes under DTU. DTU does still run the UNEP Risø Centre (also the UNEP DTU Partnership), now known as the UNEP Copenhagen Climate Centre.
[558] Aalborg University and DTU

(vocational) training and have been the forerunners in the formation of master and PhD graduates with a specialisation in various aspects of wind energy.[559]

Networks are also well functioning. There is strong collaboration between universities, industry, and technology users.[560,561] The DTU (Risø) has a Centre for Technology Entrepreneurship that teams up students and researchers with entrepreneurs, with the purpose of realising wind-related start-ups; Aalborg University collaborates with electric utility Dong Energy; Wind turbine manufacturer Vestas sponsors PhDs at Aalborg University[562]; and wind turbine manufacturers like Vestas, Siemens, and LM have offices at DTU (Risø) and in Aalborg.[563] Networks for innovation collaboration also spread internationally. For instance, Denmark has been an active member of the International Energy Agency Technology Collaboration Programme on Wind (IEA Wind TCP).[564,565]

The two largest public funding programmes in Denmark are the Energy Technology Development and Demonstration Programme (EUDP), administrated by DEA, and the Innovation Fund Denmark (IFD). Moreover, wind energy is supported via "green labs" promoting large-scale test facilities for climate technology demonstration.[566] In addition to public funding for R&D from energy and environmental taxes, many pension funds in Denmark invest in wind energy due to the widespread perception of wind being a safe business. While renewable energy is often perceived as unknown and risky by the financial sector, this is different in Denmark, as a result of the decades-long history of wind energy in the country.

Local circumstances, such as the Danish climate and a lack of fossil fuel resources have also been important incentives for the development of wind energy in Denmark. Denmark has a long coastline with consistent and strong winds, and no other natural (commercial) energy resources such as coal, gas, nor the geographical conditions for hydropower[567]. These conditions prompted Danish scientists and engineers to look for and experiment with wind technology from early on.

Table 12 summarises the main historical events shaping the Danish wind innovation system.

[559] Wieczorek et al (2015)
[560] Wieczorek et al (2015)
[561] Kamp (2008) Socio-technical analysis of the introduction of wind power in the Netherlands and Denmark. International Journal of Environmental Technology and Management (9), p.184.
[562] The Vestas Power Programme (2008-2013), for instance, had 10 PhD positions on 3 main topics: power electronics, power systems and electrical energy storage. It aimed to:
1. Identify the most suitable converter technology and control strategy for large turbines in large wind farms;
2. Assess the impact of large integration of wind power on utility stability and reliability; and
3. Determine the most suitable storage technology to enable higher wind energy grid integration.
See: https://vbn.aau.dk/en/projects/vestas-power-programme
[563] Wieczorek et al (2015)
[564] The IEA Wind TCP is an international cooperation of 23 countries and sponsor members that share information and research activities to advance wind energy deployment.
[565] IEA Wind TCP (2022) Wind Energy in Denmark. Available at https://iea-wind.org/about-iea-wind-tcp/members/denmark/
[566] IEA Wind TCP (2022)
[567] Vestergaard, J., Brandstrup, L., Goddard, R (2004). A Brief History of the Wind Turbine Industries in Denmark and the United States. Academy of International Business (Southeast USA Chapter) Conference Proceedings, November 2004, pp. 322-327.

Table 12 A timeline of wind energy in Denmark.[568]

table 1. Timeline: A brief history of wind power in Denmark.	
Year	**Key Events and Political Decisions**
1891	Wind turbine by Poul la Cour
1903	Danish Wind Electricity Company (D.V.E.S.) founded
1914	1914–1918: World War I
1919	Wind turbine with aerodynamic wings; design J. Jensen and P. Vinding
1939	1939–1945: World War II
1950	The Vester Egesborg turbine
1952	Application for Marshall Plan support for wind power research
1963	*Silent Spring*, book by Rachel Carson
1973	90% of the total national energy consumption based on imported oil
1973	First international energy crisis
1976	Danish Energy Agency established
1978	The Tvind turbine, the largest in the world at the time
1979	Second international energy crisis
1979	Public protests against nuclear power
1979	Danish Energy Policy 1979
1985	Parliamentary decision: "no" to nuclear
1987	The *Brundtland Report*
1990	Energy 2000, the first plan for low-carbon energy transitions in the world
1991	Vindeby Offshore Wind Farm, the first offshore wind farm in the world
1992	United Nations Framework Convention on Climate Change
1997	The Kyoto Protocol implements objectives of the United Nations Framework Convention on Climate Change
2000	13% of the total national electricity consumption supplied by wind power
2004	Energy Agreement
2006	*An Inconvenient Truth*, book by Al Gore
2008	2008–2011: Energy Agreement and Renewable Energy Act
2010	Anholt Offshore Wind Farm; the largest in the world at the time
2012	2012–2018: Energy Agreement
2015	Paris Agreement signed by 197 countries
2018	46.9% of the total national electricity consumption supplied by wind power
2018	Energy Agreement
2019	Climate Act

3.6.4 Description of the initiatives

The successful development of the wind energy innovation system in Denmark was the result of two complementary processes: proactive, consistent and systematic government planning and interventions (top-down) and bottom-up experimentation via local entrepreneurs and cooperatives. These are explained in subsequent sections below, though it is important to note that their success was due to their interaction and complementarity.

3.6.4.1 Bottom-up community initiatives in rural areas

In Danish rural areas, wind energy developed as a solution for rural development. In 1881, Poul la Cour, a local meteorologist, natural science professor and inventor, constructed the first wind turbine to produce electricity. His background in meteorology attuned him to the possibilities of using wind for electricity generation rather

[568] Johansen (2021)

than pumping water or milling grain, a concept rejected in other countries at the time, due to low efficiency. It also led to future work with wind tunnels and aerodynamics for windmill design.[569]

La Cour aimed to provide rural populations with a means of energy access that would allow for the mechanization and modernization of farming practices, as well as provide heat and light.[570] La Cour taught courses for "wind electricians" at the local 'folk high school'[571] and, in 1903, he established the Danish Wind Electricity Company (D.V.E.S.), together with some of his students and other partners. D.V.E.S provided training to electricians in rural areas on how to build and operate small wind energy plants. By 1918, 120 wind-powered electricity generation plants already delivered 3% of Denmark's total national electricity use. About 25,000 private farms deployed small private wind turbines for powering machinery.[572]

By the 1930s, wind energy plants had become common in the Danish countryside. There was much experimentation with emerging wind energy technologies by grass-roots entrepreneurs. The Danish association for wind energy was created and received state support in 1919. In this period, the development of the Danish wind energy industry was led especially by companies such as Lykkegaard Ltd.[573]and cement manufacturer FLSmidth, in cooperation with aircraft manufacturer Kramme & Zeuthen.[574] However, during the inter-war period, decentralized wind energy lost terrain to centralized coal-fired power stations with the expansion of the national grid. It did, though, help alleviate the effects of power outages during the second world war.[575,576]

After World War II, another of la Cour's former students initiated an R&D programme on wind energy. His efforts led to the realizatin of the Gedser machine in 1959, with funding from the Danish Association for power stations. This formed the basis of the modern wind turbine. Based on the knowledge generated from the experience with the Gedser mill, around ten companies for small wind turbines had developed by 1978. These companies built on existing knowledge in agricultural machine manufacturing to learn how to make wind turbines, often by trial-and-error.[577] These companies gained access to knowledge about earlier wind turbines during so-called Wind Meetings, where knowledge and experience were shared between wind turbine manufacturers, owners and researchers.[578]

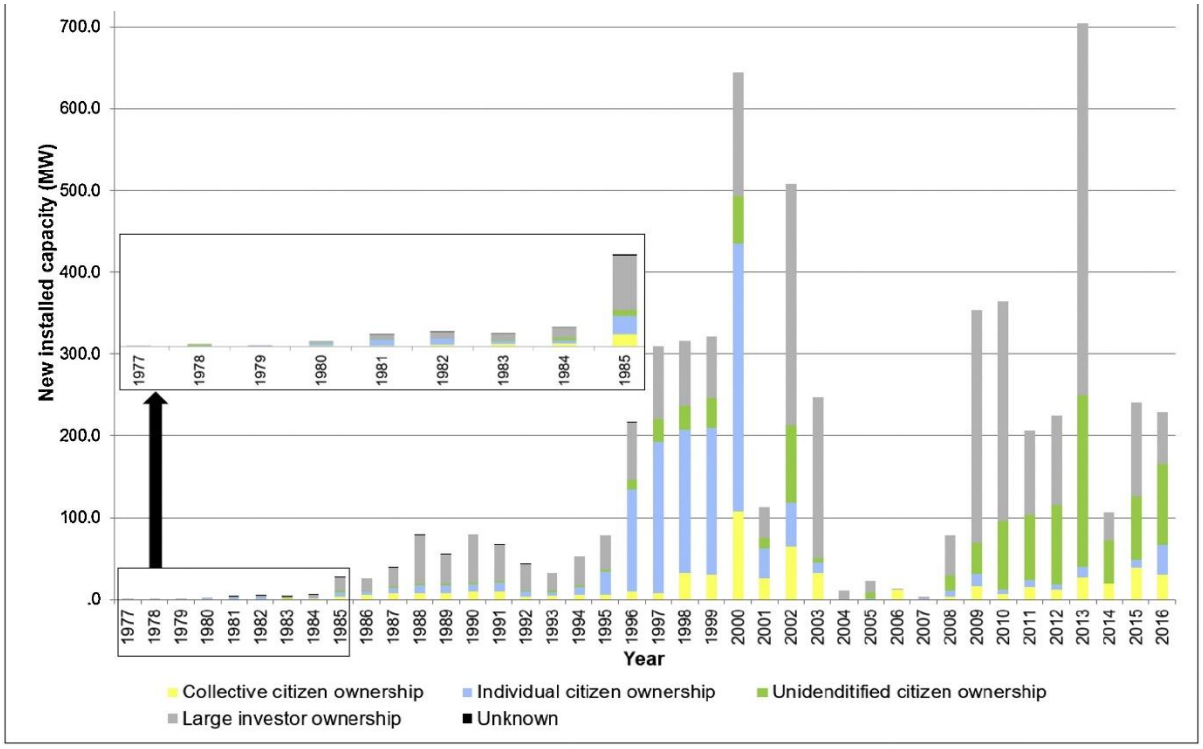
However, electricity generation costs of the Gedser mill was twice that of oil or coal-based electricity.[579] As a result, the Danish Association for power stations came to see wind energy as uncompetitive.[580] Those concerns led to a halt in wind energy research until the 1970s, when the first energy plan resumed funding for wind energy R&D and created incentives leading to the formation of wind energy cooperatives (see also the next section).

In the 1980s, environmental awareness and anti-nuclear sentiments were growing in Denmark. Renewable energy sources, including wind and solar, became widely supported by local communities as locally available "green" and sustainable energy resources.[581] This, together with the support from the national energy plans, resulted in a more favourable environment for wind energy. By the late 1990s, there were over 2,100 cooperatives, including more than 100,000 families owning almost 90% of the 6,300 wind turbines in operation

[569] See e.g.: Gipe P, Möllerström E. An overview of the history of wind turbine development: Part I—The early wind turbines until the 1960s. Wind Engineering. 2022;46(6):1973-2004. doi:10.1177/0309524X221117825,
Warnes, K., Windows into History: Poul la Cour pioneered wind power in Denmark,
https://windowstoworldhistory.weebly.com/poul-la-cour-pioneered-wind-power-in-denmark.html
[570] Johansen (2021)
[571] Folk high schools (in Danish: Folkehøjskole) are institutions for adult education that generally do not grant academic degrees. https://danishfolkhighschools.com/about-folk-high-schools/what-is-a-folk-high-school
[572] Johansen (2021)
[573] Founded by one of la Cour's former students.
[574] Vestergaard et al (2004)
[575] Johansen (2021)
[576] Vestergaard et al (2004)
[577] Kamp (2008)
[578] Kamp (2008)
[579] Johansen (2021)
[580] Vestergaard et al (2004)
[581] Johansen (2021)

in the country[582,583]. This strong community-ownership and resulting benefits provided substantial public support for wind energy and supporting policies in the country.[584]

Figure 19 Installation of wind capacity in Denmark by type of owner[585]



3.6.4.2 Government initiatives: the energy plans

Government actions supported the bottom-up developments described in the previous section, for instance providing financial support for the Danish association for wind energy was created and incentives for the formation of local wind energy cooperatives.

Since the 1970s, the contribution of the Danish government to the development of a wind energy TIS took place through the national energy plans. The first energy plan (of 1976) aimed to provide energy security in the context of the first oil crisis. Wind energy was seen as a solution for reducing energy dependency and an alternative to nuclear energy, which faced public opposition in Denmark at the time. Reports from independent energy experts helped to put wind energy forward as a key alternative.

The most relevant outcomes during this period were the creation of an energy tax and the establishment of the Ministry of Energy[586] The creation of the energy tax provided financial support for public research, spreading the costs among all electricity customers. The DTU was the key actor to receive funding for research while MoE was in charge of coordination. MoE envisioned a wind energy system based on large-scale wind parks built by consortia of large Danish firms and owned and operated by utilities. As a result, government-funded research at this time focused on the development of large-scale wind turbines.[587]

A multi-stakeholder collaborative approach was strongly present during this period. For example, in the late 1970s, companies were reluctant to build Nibe turbines due to perceived risks. Risø, DTU and the SEAS utility

[582] IRENA-GWEC (2013)
[583] Johansen (2021)
[584] IRENA-GWEC (2013)
[585] L. Gorroño-Albizu, K. Sperling, S. Djørup, 2019, The past, present and uncertain future of community energy in Denmark: Critically reviewing and conceptualising citizen ownership, Energy Research & Social Science, Volume 57, 2019, 101231, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2019.101231.
[586] IRENA-GWEC (2013)
[587] Kamp (2008)

got involved to help partially finance the wind turbines. When the wind energy department was created at Risø, funding constraints encouraged collaboration with wind turbine manufactu.res to ensure additional sources of funding. This facilitated the exchange of knowledge and made learning-by-interacting very effective.[588]

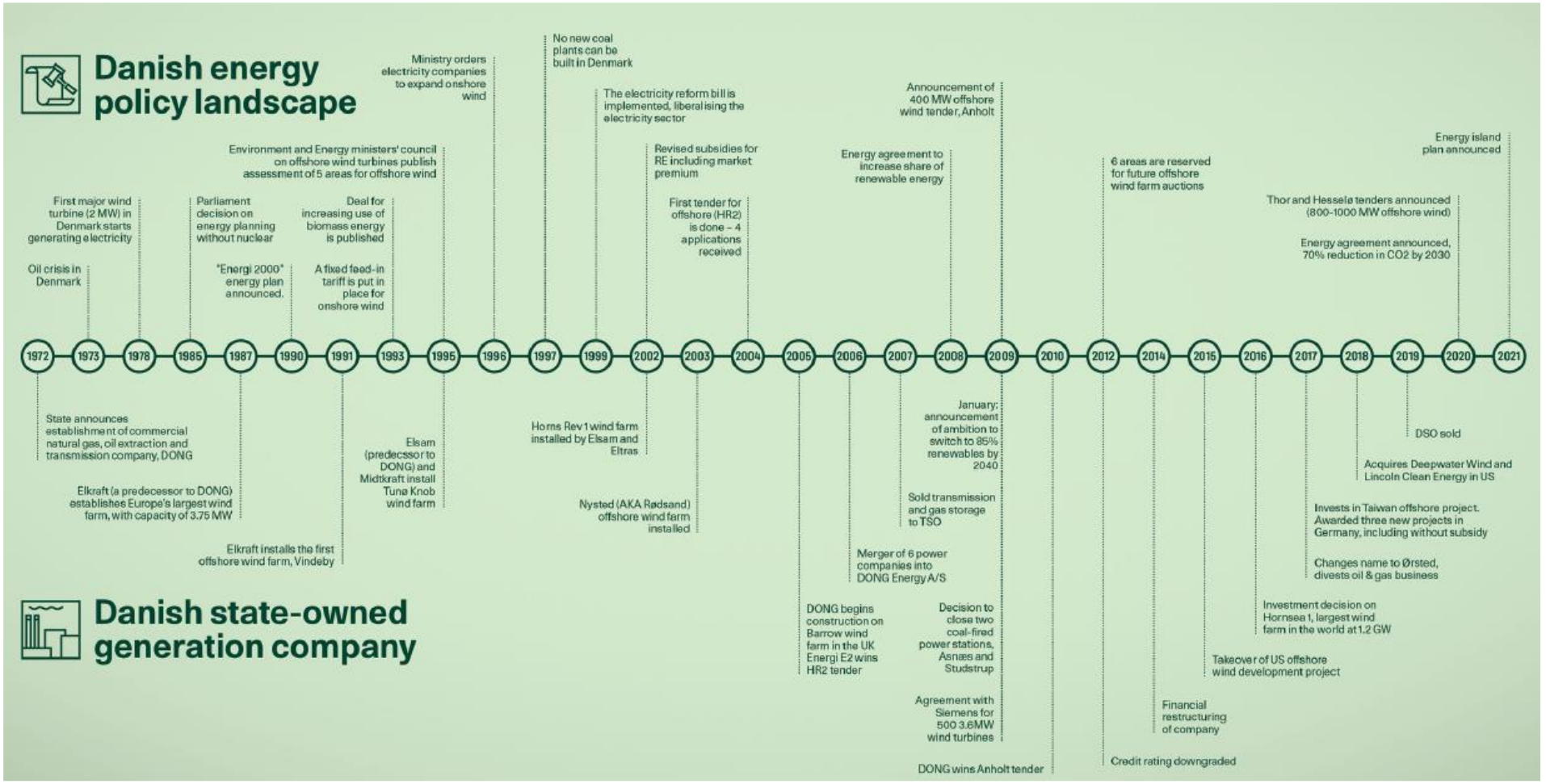
Policies in the 1980s consolidated the establishment of a domestic wind industry, helping to create a market for wind turbines and renewable electricity. The second energy plan created tax incentives for cooperatives and introduced the option that allowed them to sell excess electricity to the grid. In addition, it established the first subsidies for construction and operation of wind parks. This led to an explosion in the number of cooperatives and installation of wind energy capacity, helping the Danish industry to increase its scale.[589]

In addition to domestic trends, subsidies introduced for wind energy in California increased Danish exports of wind turbines. This was facilitated by publications of the Danish Windmill Owners Association on the performance of several types of turbines, which helped to create a good reputation for Danish wind energy technology.[590] After sales to the California market decreased in 1985, the Danish government created the "100 MW agreement", aiming to increase the domestic market by setting clear targets for additional wind energy capacity in the upcoming decades.[591] In 1988, subsidies were reduced since the domestic market was already established and technology developments were deemed to have made wind energy "naturally attractive". R&D subsidies and grants for replacing aging turbines remained. Moreover, the government started to establish legal requirements for utilities to purchase the electricity generated by wind energy producers.

Wind energy gained even more importance in the early 1990s, when the third national energy plan introduced specific targets for the expansion of wind energy to 10% of national electricity generation to help achieve emission reduction goals agreed under the Kyoto Protocol. To achieve the wind energy target, the plan set the price for wind-based electricity at 85% of retail electricity rates to make wind energy more attractive and it guaranteed interconnection to the grid for wind parks. In addition, the plan established public planning procedures to explore any latent wind energy potential. These procedures involved public hearings, which helped to coordinate priorities and actions among actors and promoted public acceptance of wind energy through participation in planning procedures. A fixed feed-in-tariff was later introduced, decoupling the wind electricity price from retail prices, and refunds from energy and carbon taxes were provided. This substantially increased revenues for wind power producers.[592]

[588] Kamp (2008)
[589] IRENA-GWEC (2013)
[590] Kamp (2008)
[591] These targets were then updated – and increased – in 1990 and 2000. Source: IRENA-GWEC (2013)
[592] IRENA-GWEC (2013)

Figure 20 Key milestones in Denmark's transition to green energy – 1972-2021[593]



[593] State of Green, 2021, From black to green – a Danish sustainable energy growth story A case study of how an energy utility can transition from fossil fuels to renewable energy and the enabling regulatory framework that made it possible, see: https://ens.dk/sites/ens.dk/files/Globalcooperation/sog_fromblacktogreenreport_210x297_v08_web_spreads.pdf

As part of the efforts to harmonise and liberalize the EU's internal energy market, Denmark went through a liberalization period in the 1990s which led to major reforms in its energy sector. As part of these reforms, the FiT was halted and the guarantee for interconnection was removed. These measures were replaced by a Renewable Portfolio Standard (RPS). Despite the RPS, the following period saw a stagnation in the Danish wind energy sector.[594] This was caused by the political views at the time, requiring renewable energy to be able to compete in the market. The renewable energy premium under the RPS was capped, and interconnection was no longer ensured.[595]

In the mid-2000s, some measures helped overcome this stagnation. Megavind, a public–private partnership for supporting the development of wind power in Denmark, was established in 2006 as part of a plan to promote eco-efficient technologies.[596] In addition, the government approved plans for two offshore wind parks, while increasing targets for renewable energy. It also created an environmental premium to be added to the electricity market price and introduced a compensation for grid balancing costs.[597] RD&D funding for energy technology was increased, and renewable electricity tariffs started to be established via special tenders managed by DEA. In addition, the government created a Public Service Obligation that would help finance grid connection.[598]

A new energy plan (the 'Energy Agreement') in 2012 established an ambitious target for wind energy to account for 50% of national electricity generation by 2020, and 3300 MW in new installed capacity, financed by the PSO. In 2018, the updated Energy Agreement established a target for 55% of the country's energy needs to be met by renewable energy by 2030, mainly through wind and solar energy.[599] Moreover, in the Climate Agreement from 2020 it was decided to initiate the development of two energy islands (located in the North Sea and in the Baltic Sea) using offshore wind.[600]

This systematic establishment and revision of clear and ambitious national targets, together with financial and regulatory incentives successfully contributed to the uptake of the Danish wind energy sector after the stagnation period.[601]

3.6.5 Assessment of the initiatives

Bottom-up experimentation contributed to knowledge development and positive externalities in the first half of the 20th century. However, developments stagnated due to uncompetitiveness of wind energy in the liberalised, centralised, coal-dominated electricity market. Top-down interventions from the government helped overcome this by establishing favourable regulations, creating a better market for renewable energy, increasing the legitimacy of wind energy in national energy planning, providing coordination and a direction for the search nationally, and mobilizing funding and subsidies for R&D and deployment of wind energy technologies. The interaction between top-down interventions and bottom-up initiatives has led to the establishment of a wind TIS where local cooperatives have high degrees of ownership and where wind energy is aligned with local societal goals of energy access and sustainable energy, which in turn provided widespread public support for the development of wind energy in Denmark.

Knowledge development and diffusion Both bottom-up and top-down initiatives contributed to knowledge development. At the beginning, the work of individual innovators was crucial to develop the knowledge on wind turbines as we know them today. Especially Prof. la Cour played a key role in knowledge diffusion, both at the folk high school (where many of his former students followed in his steps in the wind sector) and the trainings provided by his company in rural areas of Denmark. R&D funding from the government and private companies contribute to set up wind research in Danish universities, who are also a key mechanism of knowledge diffusion via wind-focused educational programmes. *The* specialist publications, the Wind Meetings, the organization of public hearings and the collaboration networks between companies and universities have been main contributors to knowledge diffusion among knowledge developers and users.

[594] Legislation to adopt the associated green certificate trading scheme was not adopted. IRENA-GWEC (2013)
[595] IRENA-GWEC (2013)
[596] Wieczorek et al (2015)
[597] Paid by the grid operator to electricity producers, suppliers or (large) consumers for adjusting their supply/ demand to help balance the electricity grid.
[598] IRENA-GWEC (2013)
[599] IRENA-GWEC (2013)
[600] IEA Wind TCP (2022)
[601] IRENA-GWEC (2013)

Entrepreneurial experimentation Entrepreneurial experimentation took place mainly by local cooperatives and grass-roots entrepreneurs, initially driven by concerns related to economic development and energy access in rural communities. The Gedser mill was a milestone for creating knowledge and experimentation with the 3-blade horizontal axis wind turbine design that became dominant. Later, multi-stakeholder partnerships were crucial to further experimentation with wind technologies, for instance the case of the Nibe turbines and university-industry collaborations, as well as public-private partnerships like Megavind.

Market formation Despite the initial success of the bottom-up development of wind energy technologies in the early 20th century, wind-based electricity was very much seen as uncompetitive at the time, which became a barrier for further development and uptake of wind energy technologies. Later on, government policies and regulations played a major role in creating incentives to develop a domestic market for wind energy.[602] The development of international markets also played a key role for the development of the wind industry in Denmark, first via subsidies in the California market, and later with the introduction of targets for wind energy in many countries around the world to help meet their GHG targets. The growing international market allowed the Danish industry to keep growing, with close to 100% wind turbines manufactured in Denmark being exported between 2004-'13.[603]

Influence on the direction of the search Target setting under the national energy plans helped shape expectations around wind energy becoming a major source of electricity generation in the country. This helped to reduce uncertainty about the future viability of wind energy. The coordination of R&D programmes by MoE contributed to a focus on the development of large-scale wind turbines and the envisioning of a system composed by large utility scale producers. This was however different from the vision of local communities, who envisaged a system based on cooperative ownership. A mix of these two visions is what was realised in the end. This can, in part, be explained by public planning procedures that promoted the engagement of both government and local stakeholders when planning for the development of the wind energy system. La Cour's wind turbine and the Gedser- mill were important developments that contributed to provide an initial direction to future technological change that further policies could build on. Specialist publications contributed to shape expectations about technical progress by highlighting recent developments and providing statistics and information about the available technologies.

Resource mobilization The implementation of energy and environmental taxes contributed to the mobilization of resources for energy R&D, including wind energy. Consumers also contributed to promote wind energy via the PSO, which helped to finance e.g., grid connection for wind parks. Private companies funded deployment and experimentation already early on. Currently, they are an important source of funding for research done at universities via industry-university collaborations. This type of multi-stakeholder collaboration was a key success factor for reducing risks and allowing the Nibe turbines project to move forward. This innovation system function also impacts other functions. Tax incentives for cooperatives helped them increase their revenues and hence creating positive externalities. Budget constraints which required universities to look for funding from industry helped to establish knowledge-sharing networks which now support the well-functioning knowledge sharing and learning by interacting in the Danish TIS.

Legitimation The government contributed to legitimation of wind energy in Denmark by including clear targets for the technology in its long-term planning, and systematically revising them to increase ambitious levels when needed. Studies from independent experts helped to make wind energy an attractive alternative to nuclear energy in the 1970s. The oil crisis put the downsides of international energy dependency high on the agenda, increasing the legitimacy of other energy technologies. Specialist publications helped to show that Danish wind energy technologies could offer a cost-effective solution for electricity production. Increase in environmental concerns regarding both climate change and nuclear energy led countries to include wind energy in their national planning to help achieve environmental and energy security goals. A participatory approach to energy planning, together with the local benefits from community ownership, helped increase public acceptance for wind energy, resulting in relatively low resistance compared to other countries. That the sector is responsible for substantial job creation has also helped legitimate the technology.

Development of positive externalities The successful development of the wind energy sector in Denmark can for a significant part be explained by the development of positive externalities. From the beginning, benefits such as rural development, energy access, and the availability of a back-up for the national grid were main drivers for

[602] For instance by implementing regulations that required utilities to purchase electricity from wind energy producers, establishing competitive prices, providing subsidies and tax exemptions, as well as guarantees for grid connection.
[603] IRENA-GWEC (2013)

the development of the first wind turbines and the establishment of national manufacturers. The possibility to increase energy security with an environmental-friendly and safe resource was the main driver for support for wind energy after the 1970s. Today, the fact that the wind industry is a major export industry employing a large number of people is a main contributor for the public support for wind energy technologies in Denmark. That local cooperatives own a large part of the wind-based electricity production capacity provides an additional source of revenues for communities in the countryside, which also strongly increased public support, facilitating more ambitious policy making.

Table 13 summarizes the structure-function coupled analysis of the wind energy sector in Denmark.

Table 13 Structure-function coupled analysis of the Danish wind energy initiatives

Function		Structural element	Interventions in the Danish wind energy innovation system
F1	Knowledge develop-ment and diffusion	Actors	• Knowledge development and diffusion via individual scientists in rural areas (e.g. in the Askov Folk High School and via the D.V.E.S) contributed to increasing the capabilities of local communities in regards to wind energy production, which later resulted in a TIS with strong community ownership • The government established R&D funding lines, promoting knowledge development at universities • Experimentation by small companies contributed to knowledge development about small-scale wind turbines • Creation of Master's degrees, PhD and technical education programmes at universities allow for formation of wind energy capabilities in system actors
		Institutions	• Planning procedure /public hearings allowed for more prompt knowledge diffusion between government actors at different levels and local communities
		Interactions	• The Wind Meetings and specialist publications formed a strong network for knowledge diffusion • University-industry interactions contribute to feedbacks on knowledge development between knowledge producers and users and helps to diffuse knowledge among actors
		Infrastructure	• Creation of university research centers on wind energy helped to develop/diffuse knowledge in academic institutions and via industry collaborations
F2	Entrepre-neurial experi-mentation	Actors	• Individual scientists played a key role in promoting early bottom-up experimentation • Companies from rural areas wishing to become turbine manufacturers promoted experimentation in manufacturing, allowing them to learn "on the go"
		Institutions	• Experimentation came first to provide energy access or back-up to centralized power generation. • Early experimentation in rural areas contributed to the formation a wind TIS with strong community ownership
		Interactions	• D.V.E.SS was formed to promote experimentation with wind technologies in rural areas. Creation of associations/cooperatives also strengthened networks • Financing of some demonstration projects by multi-stakeholder partnerships strengthened interactions between actors, promoting experimentation
		Infrastructure	• The 1st wind turbines in Denmark resulted from entrepreneurial experimentation. The Gedser mill esp. was a milestone for modern wind turbine design
F3	Market formation	Actors	• The government played a major role in setting the conditions that enabled wind energy to become competitive and have a market. This enabled the cooperatives to further expand their wind energy production, which then helped to boost the local wind turbine manufacturing industry
		Institutions	• The creation of policies and incentives, especially energy taxes, subsidies, environmental premiums, guarantees for grid connection, etc., were crucial for creating a market for wind energy, which was seen as uncompetitive at the beginning
		Interactions	• Interactions at the international level also contributed to demand for the wind energy industry in Denmark, first with subsidies in California, and later with other countries' increasing ambition to deploy wind energy technologies for their mitigation targets
		Infrastructure	• Subsidies substantially increased the deployment of wind parks, which now account for half of the Danish electricity generation
F4	Influence on direction of search	Actors	• MoE, coordinating government-funded R&D, played a key role in the direction of knowledge development at universities, especially for large-scale wind turbine systems • Local cooperatives and scientists, together with smaller manufacturers contributed to a vision of wind energy as a solution for local socio-economic development, entailing a more community-owned system with smaller-scale turbines • Independent experts and local communities that opposed nuclear energy helped making wind energy an alternative for reaching Danish energy goals
		Institutions	• National energy plans set long-term targets for wind energy, helping to align expectations around the technology becoming a key solution for energy security, environmental sustainability and economic development • International agreements increased expectations of the role that wind energy could play in future energy systems • Specialist publications helped to set standards and best-practices and shape expectations around the future development of wind energy technologies
		Interactions	• Interactions via the Wind Meetings helped share knowledge and guide expectations around wind energy production

			• Public hearings included in planning procedures strengthened coordination between government and local actors, making wind energy planning more participatory and including different stakeholder perspectives
		Infrastructure	• The first turbines developed through experimentation in rural Denmark were major contributors to setting the direction for the further development of wind turbines as the origin of design standards and procedures (e.g., the currently dominant three blade horizontal axis design)
F5	Resource mobilization	Actors	• Multiple actors contributed to mobilizing resources, including local cooperatives, individuals, companies, universities, and the government • Consumers also played a key role in mobilizing resources in the Danish wind TIS following the establishment of energy taxes and PSOs
		Institutions	• The establishment of energy and environmental taxes was a major contributor to mobilizing funding for R&D in wind energy in Denmark • The creation of a PSO contributed to financing of grid connection costs for wind parks • Establishment of FiTs, subsidies for building/operating wind parks, and replacing aging turbines helped to mobilize resources for wind energy producers
		Interactions	• University-industry interactions contributed to mobilize resources for funding R&D activities where public funding was not widely available • Multistakeholder partnerships also contributed to mobilizing funding, often by reducing risks for private companies e.g., the case of the Nibe turbines
		Infrastructure	• Resource mobilization was a key function allowing the deployment of wind energy technologies, contributing to make wind energy a major source of electricity generation in Denmark
F6	Legitimation	Actors	• Scientists and local entrepreneurs were the first to use wind energy for rural development and energy access. They also showed that the technology worked and could indeed be integrated into the energy system • Independent experts and environmentalists provided legitimacy by emphasizing wind as the best alternative to nuclear and fossil fuels • Government provided legitimacy to wind energy by making it a key component of the national energy plans
		Institutions	• National energy plans including specific targets for wind energy generation contributed to wind being seen as a legitimate energy supply technology • Specialist publications contributed to legitimate Danish wind turbines by sharing information on their good performance
		Interactions	• Public hearings during planning processes contributed to increased legitimacy of wind technology in energy planning • The Wind Meetings helped provide information about wind energy as a viable solution to energy security in Denmark • Collaboration within wind cooperatives helped increase awareness about the benefits for rural areas, contributing to legitimacy of wind energy
		Infrastructure	• Dependency on foreign energy resources and high availability of wind energy resources helped provide legitimacy to wind energy technologies as a solution for energy security and energy access in Denmark • Lack of reliable access to the national energy grid led rural communities to look for alternatives for energy access and economic development
F7	Develop-ment of positive externalities	Actors	• Providing means for energy access and rural development to empower local communities was the main aim of the development of wind energy in rural Demark by scientists and entrepreneurs
		Institutions	• Strong community ownership in the Danish wind TIS ensures that wind energy also helps local communities meet societal goals • Tax exemptions and subsidies increased revenues for cooperatives
		Interactions	• Actors concerned about rural development and environmental sustainability contributed to the formation of networks and associations that would then increase political support for wind energy • Collaboration between university and industry had a clear aim of knowledge development that would also be useful to technology users, so that resource mobilization would be easier
		Infrastructure	• Deployment of wind energy allowed small rural firms to upgrade their production process, and provide more reliable energy access to rural communities • Wind energy development allowed Denmark to reduce international energy dependency by establishing a local renewable energy system • Wind energy played a key role in decarbonization of the Danish electricity grid, while providing a more socially accepted alternative to nuclear energy

3.6.6 Role of the initiative in Denmark's NDC

As discussed in Section 2.6.4, climate change mitigation goals have been an important driver since the 1990s, and wind energy targets have been increasing in ambition since then to align with increasingly ambitious mitigation targets.

Denmark's NDC is submitted by the European Union on the behalf of all of its member states and many of the energy and climate policies implemented in Denmark are (transpositions of) measures agreed at the European level for all member states. The EU has a binding target of reducing GHG emissions by at least 40 % by 2030 compared to 1990 levels. This 40% reduction established the basis of the EU's contribution to the Paris Agreement.[604] Since 2013, the EU's GHG emissions are split into two parts[605]:

- GHG emissions in all EU member states that are covered by the EU Emissions Trading System (EU ETS), with rules and targets ser at the EU level; and
- 'Other' GHG emissions, which fall under the responsibility of the individual member states in which they occur, but with (differentiated) targets also agreed at the EU level. Policies to address these emissions are a mix of EU harmonised policies and domestically developed policies.

Electricity generators emitting GHG emissions are covered by the EU ETS, renewable electricity generators are not. Member states do have binding national renewable energy targets, laid down in EU legislation.[606]

At the national level in Denmark, the Climate Act approved in 2020 also sets more ambitious targets for the reduction of the country's total national emissions. It stipulates a 50-54% emission reduction for 2025 and a 70% emission reduction for 2030, when compared to 1990, and climate neutrality by 2050. The Act establishes a rolling target setting mechanism for five years, 10 years in advance[607]. The deployment of renewable energy, in particular wind energy, has widespread support as a means of meeting the Danish 70% emission reduction target. The development of large-scale wind energy, including new offshore wind farms, is expected to play a major role in reaching this and future targets, in Denmark as well as the EU.

3.6.7 Key success factors and lessons learned

For successful innovation, both technology-push and demand-pull policies are needed. The successful development of the wind energy innovation system in Denmark is the result of, on the one hand, research and development and entrepreneurial experimentation efforts that allowed wind energy technologies to generate electricity efficiently, and on, the other hand, multi-level market creation policies that generated the right incentives for the development of commercial wind energy generation capacity and helped to create a market for renewable energy.

A dynamic interaction and synergy between bottom-up and top-down measures facilitates innovation. Bottom-up initiatives helped adapt wind energy technologies better to local interests and needs, for instance in terms of energy access and the economic development of rural areas. Nevertheless, on its own, this was not enough to make wind energy competitive in the market. Consistent and coherent government policies were crucial for setting up legislation to achieve that[608] and to establish long-term targets to help align expectations regarding

[604] Danish Ministry of Climate, Energy and Utilities (2019). Denmark's integrated national energy and climate plan under the regulation of the European parliament and of the council on the governance of the energy union and climate action. Available at https://kefm.dk/media/7095/denmarks-national-energy-and-climate-plan.pdf

[605] Each is covered by different legislation, the EU Emissions Trading (EU ETS) Directive (and its implementing legislations and delegated acts) and the Effort Sharing Regulation (ESR), respectively. Denmark's domestic 2030 target for non-ETS emissions amounts to -39% compared to 2005 levels. Source: Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013.

[606] Denmark's renewable energy in 2020 (as the share of renewable energy in gross final energy consumption) under the 2018 Renewable Energy Directive amounts to 30%. Note that this is not limited to renewable electricity. Source: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

[607] Grantham Research Institute on Climate Change and the Environment. Climate Change Laws of the World: The Climate Act. Available at https://climate-laws.org/geographies/denmark/laws/the-climate-act

[608] Establishing e.g., subsidies, grid connection guarantees for wind parks, obligation to purchase power from wind producers.

the role of wind energy in the future Danish energy system. Importantly, it was the synergetic interaction between these two that provided the dynamism to innovation.

Coordination between knowledge producers and knowledge users accelerates technology development and diffusion. The role of multi-stakeholder networks contributed to the development of wind energy technologies in Denmark, be it in the early stages when pioneers engaged with local firms and communities to come up with solutions, or later via close industry-university collaboration. Specialist publications and the Wind Meetings helped to promote knowledge sharing and increase awareness about the high performance of Danish wind turbines, which facilitated their entrance into the global market.

Dynamic, evolving innovation systems continuously utilize and create new opportunities. Challenges change over time, hence new solutions are needed on a continuous basis. A system that adapts to these changes will develop new and/or better materials, products and services, creating new markets or expanding existing ones. In the wind energy sector this can be seen in the development of new materials, technologies and services in response to environmental concerns (wildlife endangerment, recyclability), stakeholder resistance (noise pollution, visual pollution), grid integration issues and financial risks. In terms of services, this can e.g. entail support for impact assessments and stakeholder engagements with e.g. visualisation tools or bird migration modelling, as well as grid integration modelling and engineering, project management or finance application support.

Sustained government and public support can provide legitimation, altering (institutional) risk perceptions of a technology. Institutional investors have long seen renewable energy generation plants as a risky investment due to unfamiliarity with the technology and its challenges. In contrast, in Denmark, the long-standing support for wind energy resulted in such credibility for the sector that many pension funds in Denmark invest in wind energy due to the widespread perception as a safe business.

Individual champions can have an important impact in driving innovation for specific technologies. As demonstrated by the role of meteorologist, inventor and science professor la Coeur, individual scientists can have an outsized role in RD&D, knowledge development and diffusion, entrepreneurial experimentation, strengthening of local communities and realisation of externalities (e.g. in the Askov Folk High School, D.V.E.S., access in rural areas).

Aligning technological development to societal goals can facilitate the formation of coalitions that provide political support and legitimacy to the new technology, while participatory approaches increase ownership and public acceptance. The goals of energy security, energy access, rural development and environmental sustainability were key drivers for the widespread public support that wind technologies had in Denmark. The strong role of cooperatives in the Danish wind energy sector as well as the participatory approaches for energy planning relying on municipalities and local public hearings has ensured strong public support for wind energy development. Public support can then act as a feedback effect facilitating the creation and implementation of additional policies that will further support the development of the TIS.

International aspects can influence the development of local innovation systems, intentionally or not. Local support for technology innovation as well as early market formation increased the country's ability to compete in international markets. The oil crisis was a crucial turning point in Danish national energy planning, resulting in a prioritization of wind energy as a renewable and environmentally sustainable alternative to oil and nuclear energy, and as a means to ensure national energy security and increase prosperity in rural areas. Subsidies in California helped to create the first market for Danish wind turbines abroad. Later, increased concerns with environmental sustainability globally, including via the UNFCCC process, helped put wind energy even higher on the agenda and helped boost the global market for Danish wind turbines. Early public support, as well as bottom-up experimentation and learning, gave Denmark the initial advantage in the wind industry, but it was their systematic continuation and reformulation that allowed it to maintain this leadership.

3.6.8 Good practices for potential replication

The above lessons learned lead to the identification of the following good practices in the Danish wind sector that might be replicable in other countries:

Ensure continuous monitoring and evaluation, providing room for realignment, adapting to evolving challenges and new opportunities. The Danish government set multiple targets for wind energy generation, increasing ambition each time. This helped to manage expectations around the future role of wind energy. This good practice of providing a long-term direction and certainty to technology developers and investors could be replicated in many different contexts, also for other technologies. Monitoring and adapting to newly emerging challenges can not only help prevent or reduce such challenges, it can also help to create new opportunities over time for new sectors and providers of materials, technologies, products and services.

Strengthen networks to ensure coordination between stakeholders. Multi-stakeholder networks facilitate knowledge sharing and coordination and facilitating the uptake of technology, e.g. though university-industry collaboration, public-private partnerships, and meetings and publications from cooperatives and associations. This also applies to a broad range of climate technologies.

Facilitate a combination of top-down and bottom-up measures. Bottom-up initiatives promote higher community ownership and allow for alignment with local interests and needs. However, such initiatives often come up spontaneously, i.e. not directed by government interventions. Policy makers can help promote bottom-up initiatives by promoting governance structures that allow for local decision-making, such as in public consultation procedures. In addition, government should ensure there are no regulatory or other barriers for local initiatives and cooperatives, e.g. so that they are allowed to compete in the market. They can also ensure that local stakeholders are heard and they have the capabilities necessary for coming up with creative local solutions and experimentation. Moreover, policymakers can guide the direction of technological change and ensure market access for new technologies by setting up supportive policies and regulations, as well as by mobilizing resources.

Ensure policies address both technology-push and demand-pull aspects. Knowledge development, improving performance and experimentation with new technologies are crucial to create legitimacy for new innovations. However, new technologies are often unable to compete with established ones, or they are not yet integrated into regulations. Proactive policy making is required to ensure these new innovations can become competitive in the market, for instance via subsidies, price premiums, regulations allowing to sell electricity back to the grid or ensuring grid connection. Moreover, by setting long-term ambitious targets, government can help to create more certainty regarding the future demand for climate technologies.

Build trust in technologies to reduce risk perception and stimulate investments. When (private or public) investors see a sector as low-risk, they are more likely to invest in it. Long-term support by government can help create legitimise sectors or technologies resulting in increased credibility and reduced risk perception. This can also be further enhanced by broad support from the general public for the technology. Increased investments, especially by institutional investors such as pension funds, can in turn further increase credibility.

Leverage international developments. Solutions to tackle national challenges can impact innovation in other countries. For instance, the creation of markets abroad in California helped the Danish wind industry attain scale. At the same time, the development of the Danish wind industry with the associated technology improvement and cost reductions now offers many other countries a viable solution to help meet their climate change targets. The situation where policies in one country contribute to strengthen innovation systems in other countries is also known from other cases, for instance for photovoltaics in China[609] and bio-ethanol in Brazil (see for the Brazil case study Section 3.4). Benefits from innovation in certain countries like cost reductions can often be captured globally given the internationalization of supply chains. Knowledge sharing via transnational networks play a role in this. However, this knowledge sharing must be not only about technical aspects, but also about e.g., policies and regulations that can promote certain innovations.

Ensure synergies between innovation policy and multiple societal goals. Wind energy development in Denmark was constantly driven by societal challenges such as those related to energy access, rural development, energy

[609] See for instance Binz, C., B. Truffer, L. Li, Y. Shi, and Y. Lu, 2012: Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China. Technol. Forecast. Soc. Change, 79(1), 155–171, doi:10.1016/j.techfore.2011.08.016. and Gallagher, K. S., 2014: The Globalization of Clean Energy Technology: lessons from China. MIT Press, London, England, 261 pp.

security and environmental sustainability. These societal goals contributed to increasing public support for wind energy, resulting in the promotion of innovation and ambitious target-setting. Ensuring synergies between societal goals in innovation policy design can create feedback effects, as achieving societal goals such as socio-economic development and environmental sustainability can increase support for new policies in the future. This is especially important in the context of achieving the multiple goals entailed in sustainable development.
Here it should be noted that the situation of Denmark as a developed country is different in many ways to that of many developing countries. However, as the similar experience with the Brazilian bio-ethanol activities (see Section 3.4) demonstrates, lessons and good practices may also apply in a developing country context.

4 Lessons learned and good practices

4.1 Cases in comparison

In the previous section, a number of case studies has been assessed, varying in focus, scope, approach and national context. They cover mitigation- and adaptation-related activities, different sectors, top-down and bottom-up approaches to stimulate innovation, focus on different barriers to innovation and different functions of innovation systems and different country groupings. Here, the case studies are compared for a number of important characteristics, to facilitate how lessons learned compare across the case studies, and to which extent they can be generalised into good practices. It should be noted that while we have used the NSI framing for the analysis here, many of the key findings also align with the "transformative change" framing proposed elsewhere[610] and its key dimensions of "anticipation, experimentation, participation, and directionality".

Of the six case studies analysed, three focussed on **mitigation**, two on **adaptation**, and one (KCIC) covered both mitigation and adaptation. There are commonalities as well as clear differences between mitigation- and adaptation-focused NSIs. Adaptation initiatives are more dependent on international public funding resources than mitigation actions, where markets and the private sector plays a larger role. Market-related functions such as entrepreneurial experimentation and market formation are less developed for adaptation, perhaps as adaptation sectors lend themselves more for public investments as what adaptation sectors provide are mostly public goods for which the benefits cannot be privatised. For adaptation, international interactions are also usually less bidirectional. The first-mover cases show less international cooperation than the other cases. The adaptation and mitigation cases also share lessons learned, such as for instance the importance of integration with national objectives and the need to engage local actors (see also

Table 18).

Table 14 shows an overview of the extent to which innovation in the various initiatives is **driven top-down, from the bottom up**, or a combination of both, in each of the cases, and the main actors involved. It illustrates that for the Indian and Kenyan case studies, activities were clearly initiated, driven and coordinated by one central organization, BEE and KCIC respectively. While in both cases many other actors were involved, and had important roles to play, they generally did so in response to actions or opportunities provided by the central actor. This is different from the cases in both Brazil and Denmark, where both top-down and bottom-up activities were running in parallel, strengthening each other in an iterative process. On the ground local experimentation and entrepreneurship was supported by national policies, which led to further bottom-up level actions. In the adaptation cases in Haiti and Jakarta, the top-down and bottom-up activities also ran in parallel, but more independently, with less interaction. While here also both approaches benefit from each other, e.g. capabilities being built through the bottom-up process that benefits the likelihood that the top-down process succeeds, there is less mutual strengthening and co-evolution.

Table 14 Top-down vs bottom-up aspects across the different case studies

Case	Top-down aspects	Bottom-up aspects
India BEE	BEE acts as 'system aggregator' or coordinating agency designing and managing the programmes taking into account strengths and weaknesses of the NSI and its constituents[611]	.
Kenya KCIC	KCIC acts as an enabler or facilitator of climate adaptation/mitigation projects by establishing collaborations and generating resources,	

[610] Schot, J., and W. E. Steinmueller, 2018, Three frames for innovation policy: R&D, systems of innovation and transformative change, Research Policy, Volume 47, Issue 9, 2018, Pages 1554-1567, ISSN 0048-7333, https://doi.org/10.1016/j.respol.2018.08.011.

[611] BEE adopted a strategic and forward-looking approach by building on the strengths of the various actors and developing capabilities and networks to bridge the gaps in the innovation system.

	thereby de-risking investments and partnerships[612]	
Haiti DRR	National plan to provide coordination and establish standards and procedures, with D(G)PC [613] primarily responsible in charge of risk and disaster management	Mobilization by civil society, including local community and volunteers for instance through the Sahana Free and Open-Source Disaster Management System
Brazil bio-ethanol	National programmes such as ProÁlcool, coordination between sectors by the government, subsidies and regulations for fuel use	Experimentation by sugarcane producers and later other industry players (e.g. equipment manufacturers), coordination via multi-stakeholder networks
Jakarta urban flood manage-ment	Mostly top-down, driven by the national policy framework and its implementation at the local level, and large projects with international resources and national and local government participation	The general process of decentralization in Indonesia moved some powers and responsibilities to local agencies EWs and flood control systems developed by local agencies and other local initiatives
Denmark wind energy	National energy plans, energy taxes and subsidies, regulation of the energy sector	Experimentation in rural areas by local scientists and entrepreneurs; participatory planning; local cooperatives implementing wind farms; multi-stakeholder meetings

The above distinction in top-down versus bottom-up approach is also reflected in *Table **15***, which summarizes the role of the **main actors** involved in each of the case studies. The table also describes the extent to which those role have a legal basis. From this, it can be seen that especially for the BEE and KCIC, a main, central actor was responsible for driving developments and coordinating actions with the many actors involved in the initiatives. For BEE this had a strong legal basis in legislation, important to provide the authority to set standards, direct activities at the state level and create legitimacy. For KCIC, as an international initiative, there was no legal basis for its role. But its long-term, successful operation established credibility and resulted in governmental acknowledgment as the official implementing agency of the Promote Climate Technologies and Innovation initiative under the Kenya Vision 2030.

In Brazil, different ministries, and the regulatory agencies they established (IAA, ANP) were the main, central actors, with changing roles over time. Each of these actors, however, had broader mandates, and no single central coordinating actor for the bio-ethanol activities was established. Specific ethanol-related roles and responsibilities were laid down in various policy documents over time. This is to a certain extent similar in Denmark, with MoE and DEA having broader mandates and specific roles and responsibilities stipulated in national energy plans. Through this, both countries were able to create the conditions for bottom-up initiatives to flourish in an iterative process. In Haiti and Jakarta, national legislation established responsibilities at the national and local level, with the legal basis strengthening over time. Plans (and later laws) also established the roles of other actors, including at the local level. This was complemented with local initiatives, without central coordination, but often with international links (funding, networks, volunteers, expertise).

[612] Initially, a donor-driven, international initiative, KCIC evolved into an independent, not-for-profit organization promoting local entrepreneurship and innovation.
[613] The Directorate (General) for Civil Protection of the Ministry of the Interior and Territorial Communities

Table 15 Characterization of main actors involved in the initiatives in terms of the role and its legislative basis of leading organization

Case		Main actors involved	Lead organization				
			Y/N	Name	Status	• Role	Legislative basis
India BEE		• Bureau of Energy Efficiency, BEE • Energy auditors • Manufacturers • End users of appliances • State-level electricity distribution companies	Yes	BEE	Nodal central statutory body under Ministry of Power to institutionalize implementation of EE goals	• Organize policies, programmes for effective energy utilization, design sectoral energy utilization standards, MRV of energy efficiency improve-ments, enforcement of compliance • Promote R&D on energy conservation • Lead implementation of EE activities in NAPCC and ROSHANEE	Energy Conservation Act 2001 provides legal mandate, institutional structures, and regulatory mechanisms for BEE's policies/ strategies at national/ state levels Directs state agencies / organizations to coordinate with BEE, promote EE in states
Kenya KCIC		• KCIC • Local entrepreneurs, start-ups • Funding agencies • Technology providers	Yes	KCIC	Internationally funded consortium As of 2018L implement-ting agency of MTPIII	• KCIC provides training and market intelligence to potential start-ups and local entrepreneurs. • KCIC helps in mobilization of funds and sourcing of appropriate technologies.	No legal basis Recognized by government as official implementing agency of the Promote Climate Technologies & Innovation Initiative
Haiti DRR	Top-down	• Ministry of Interior & Communities, Dir. for Civil Protection DPC • Organizations under PNGDR, e.g. the Thematic Committee for Edu-cation and Public Awareness (CTESP), Emergency Operations Centers (EOC), local committees for disaster risk management	Yes	DPC (DGPC)	Ministry directorate, later directorate-general DGPC: autonomous body Organizations created under the PNGDR such as committees	Elaboration of national DRR and management plans, incl •Creation of coordination committees •Training and educational activities •Communication/awareness campaigns, guidelines and protocols, •Information management •Mobilization of public funding	1990 Decree gives DPC responsibi-lity for a National Disaster Plan, PNGRD specifies roles for disaster management. DRM law 2020 fo-rmalises PNGRD, gives DGPC the mandate for technical coordination, knowledge management, technical support and strengthening capa-city/mobilizing SNGRD
	Bottom-up	• Local communities • International volunteers • International donors • Sahana software foundation	No				
Brazil bio-ethanol	Top-down	• National government and related organizations • Sugar and Alcohol Institute (IAA) • National development bank (BNDES) • Innovation funding agency (FINEP) • National Council for Scientific & Technological Development (CNPq)	Yes	• Various ministries: Min. of Science & Innovation; Min of Mines & Energy; Min of Industry; Min of Agriculture • IAA, ANP	National ministires Regulatory agencies (IAA, ANP) (all with broader mandates than bioethanol)	•Elaborated national strategies for ethanol and other biofuels, defined legislation, mobilized public funding, ensured coordination between stakeholders across the system •Mobilized funding for R&D •Mobilized finance for deployment projects	No legislative basis to establish one central actor for bioethanol. Main actors have broader mandates, has been appointed in Brazil. Specific bioethanol-related roles are stipulated in several legislations including laws, resolutions, presidential decrees, e.g.

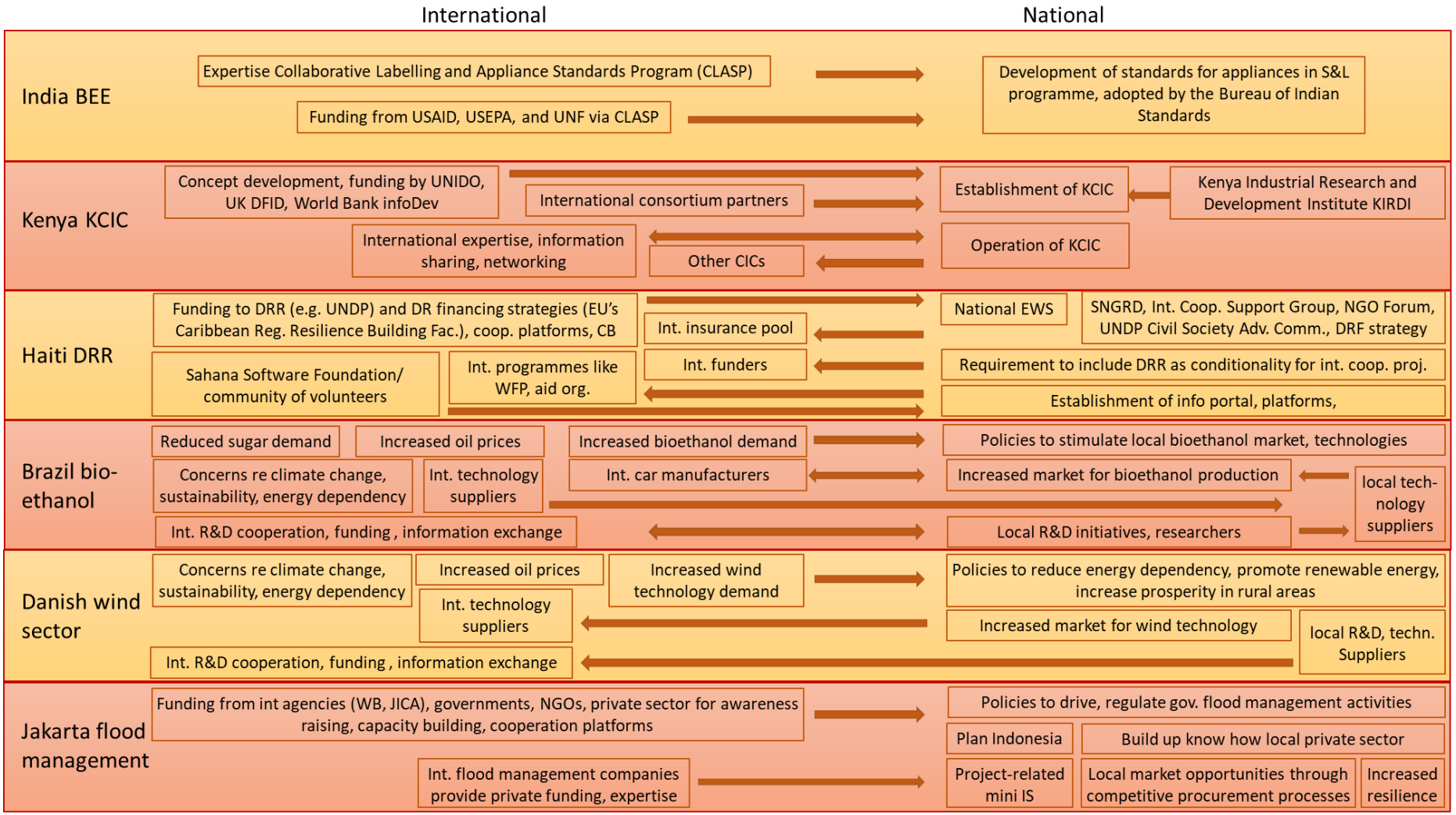
		• National Petroleum Agency (ANP)		• Other public organizations (BNDES, FINEP)		•Regulates the Brazilian oil and gas system (including transport fuels)	ProAlcool, PAISS. E.g. ANP's role in ethanol fuel regulation established in laws 12.490/2011, 9.308/2018.
	Bottom-up	Private sector (sugarcane producers, technology providers, car manufacturers), universities	No				
Jakarta urban flood management	Top-down	• Ministry of Education, Culture, Research&Technology (MOECRT) • National/Regional Disaster Management Agencies BNPB, BPBP • Regional/provincial governments • National Research and Innovation Agency (BRIN) • International funders • R&D institutions	Yes	• Ministries MOECRT • DKI Jakarta • Disaster management agencies BNPB, BPBD	National ministry Regional government (Special region) BNPB: Independent agency directly reporting to the President	• Develop/implement programmes, strategies to manage floods, impacts and adapt • Generate financial resources and procure technical know-how. • Create partnerships (incl. public-private) • Engagement with local communities, NGOs and educational institutions. • Promote related R&D and local innovation to address the challenges.	2004 National Development Planning System Law, 2007 Spatial Planning Act require government to develop socio-economic development plans,incl water management. 2007 Disaster Management Law (DML) mandates roles/responsibilities of national/local governments and others. Local government must follow DML norms for its disaster management regulations, systems.
	Bottom-up	Industry, private sector, local communities, NGOs	No				
Denmark Wind Energy	Top-down	Government: Ministry of Energy, Danish Energy Agency	Yes	Ministry of Energy DEA	Ministry Agency under MoE	MoE: • Elaborate national energy plans • Set targets for electricity from RE/wind; • Fund R&D programmes • Establish incentives, regulations • Provide coordination of energy sector DEA is responsible for, amongst others: • Regulatory authority for the grid • Establish RE supply obligations • Organize Danish energy transition • Coordinate national climate efforts • Share expertise internationally	National energy plans form the basis for the establishment of policies, taxes and incentives and created the main national authorities and governing agencies. MoE established via the first National Energy Plan (1976). Energy agreement 1986 excluded imported oil and nuclear energy from national energy mix[614]
	Bottom-up	• Entrepreneurs. cooperatives • Danish Wind Electricity Company • Danish Windmill Owners Ass. • R&D organizations, Risø, DTU	No				

[614] State of Green (2021)

As shown in Figure 21, all cases have **international linkages**, though their motive, extent and direction differs for each case. This confirms the importance of international exchanges for the development and diffusion of climate technology described in Section 2.1. All cases have links to international financial resources and interactions between local and international R&D communities. As can be expected, international financial resources are especially important for the adaptation cases (Haiti, Jakarta). A difference is that for DRR in Haiti this was predominantly from international development agencies and NGOs, while for the Jakarta case there was also strong involvement from international companies. The international interactions for bio-ethanol in Brazil and wind energy in Denmark mostly took place through international markets (for sugar, bio-ethanol, wind turbines, fossil fuels), as well as the impact of international environmental targets affecting both domestic and international markets. For the BEE, international links were more limited, focussing especially on building on international standardisation knowledge, given the size and capacity in-country, and that the benefits and costs were both concentrated in India.

While international relations can be one-directional (from international actors to domestic actors or reverse), there are also examples of bidirectional international exchanges. This can - across the cases - be seen in the interactions between national and international R&D communities. In addition, developments in Brazil influenced international technology developers (ethanol production technology, alternative fuel vehicles), while technical progress in both bio-ethanol and wind energy systems allowed more ambitious targets to be set in many other countries. KCIC is an interesting case, in this regard, as the initiative started with international funding and parties, then became more 'nationalised' (in terms of funding and actors involved), and subsequently playing a role in the development and strengthening of capabilities in other countries, through the international network of Climate Innovation Centers. In Haiti, local capabilities and tools developed with international assistance provided new information and data to international organizations, allowing them to improve their support in case of later disasters.

Figure 21 international interactions in each of the cases Note that concerns regarding e.g. energy dependence or climate change that are shown here on the international side can also exist at the national level (not shown here because of space limitations).



Financial resources for the activities covered in the case studies come from a variety of sources, both international and national, from public as well as private sources. In addition, also non-financial resources can be involved, e.g. human resources from volunteers. Specific information on the size of budgets involved is not readily available or comparable across case studies. Table 16 shows the differrences in sources, as well as the use of resources in terms of activities and beneficiaries across cases. All cases used government funding, either as part of the general budget, or generated by energy or environmental/carbon taxes, a tax on oil and gas exploration in Brazil or in the case of Haiti labour taxes. For KCIC government funding is only indirect, through the participation of government institute KIRDI[615] in the original project consortium. KCIC demonstrates a successful evolution in funding model, from (mostly) international funding leading to the establishment of KCIC, KCIC and international funding establishing KCV and KCV funding ESFM, which funds projects. In addition to traditional funding instruments (e.g. subsidies, grants, tax incentives), financial resources also come from price guarantees and PSOs (Brazil, Denmark) or revenues from tradeable credits/certificates (India, Brazil).

Funding capacity building and awareness raising is a common use for available funding in all cases, as is funding R&D. For Brazil and Denmark, resources also fund financial incentives for producers and users of sugarcane, bio-ethanol, alternative fuel vehicles and wind turbines as well as the respective end users. This also applies to EE products in India. Funding 'hardware' occurs e.g. with flood management infrastructure and EWSs in Jakarta, the government's alternative vehicle fleet in Brazil, the projects supported by KCIC and the establishment of technology parks, facilities, labs, etc (KCIC, BEE, bio-ethanol activities). Funding is also used to develop governmental institutions, plans and response strategies, especially in Haiti and Jakarta.

Table 16 Funding sources for the various case study initiatives

Case	Source of funding	Use/beneficiaries
India BEE	• Government budget • Funding opportunities through CLASP[616] (USAID, USEPA, UNF) • Carbon credit revenues • Energy saving certificate revenues	• Awareness raising campaign, capacity building with retailers/end users to create a market for EE products • Definition of standards, labels • Creation of testing/servicing infrastructure, training of energy managers, auditors and verifiers • Discounted prices for end users of EE products • Pilot installation for EE products (street lighting) • Funding for industrial EE to meet PAT targets
Kenya KCIC	• Initially international funding (UKaid, DANIDA through World Bank) • World Bank funding to launch Kenya Climate Ventures (KCV) • KCV, with KCIC convertible debt investment • Early-Stage Finance Mechanism (ESFM), with KCV and other funding	• Awareness-raising programmes on technologies, markets, knowledge/research updates • Mentorships, technical assistance and customized training to entrepreneurs • Funding of projects and ventures in early stages of innovation cycle by private sector parties[617] • Government lobby, policy advocacy, policy advise to businesses • Increased access for entrepreneurs to facilities
Haiti DRR	• Government budget, Emergy Fund (funded by tax on salaries) • International donors, e.g., UNDP, WFP, GCF, bilateral agencies (SDAC, USAID, etc.) • Risk financing istruments, supported by World Bank, EU (CCRIF, CERC[618]) • International NGOs, crowdsourcing	• Strengthening government institutions, capacity building local communities • Analysis, development of national plans, response strategies • Awareness campaigns • Educational programmes and trainings at schools and universitiesReconstruction programmes • Data collection and tool development

[615] Kenya Industrial Research and Development Institute
[616] Collaborative Labelling and Appliance Standards Program
[617] Proof-of-concept grants, seed funding, ealy-stage risk financing
[618] Caribbean Catastrophe Risk Insurance Facility, Contingency Emergency Response Component

Brazil bio-ethanol	• Government funding, incl from ANP's 1% clause[619], ProÁlcool, incubator policy PIN, • Minimum sales prices • Public funding via BNDES, CNPq[620], innovation funding agency FINEP • Private funding (companies and associations) • Decarbonisation Credits (CBIOs)	• Funding R&D, pilots and demonstration projects for ethanol production as well as use in e.g. flex fuel vehicles • Technology parks and incubators • Governmental ethanol-fuelled vehicle fleet • Financial incentives for sugarcane producers (to increase sugarcane production, expand/ adapt ethanol processing plants) and car industry (to develop ethanol-fuelled vehicles) • Subsidies for ethanol fuel consumption • Trust building & awareness campaigns for end users
Jakarta urban flood manage-ment	• Bilateral donors and multilateral agencies (World Bank, JICA, ADB) • National government • Private sector investments (national and international) • International NGOs	• Development of master plans, feasibility studies • Infrastructure investments (sea walls, dikes, floodgates, canals, reservoirs), as well as dredging and normalizing rivers • Capacity building and funding for O&M of floodgates • Technical assistance for project management, contract mana-gement, engineering design reviews, monitoring, supervision, social safeguards, resettlement plans • Knowledge generation, diffusion • Strengthening community preparedness, via implementation of EWS, flood control systems, capacity building, awareness rasing
Denmark wind energy	• Government, using energy/environ-mental tax revenues • Pension funds • Private funding (entrepreneurs, cooperatives, companies) • Consumers (via Public Service Obliga-tions (PSOs))	• Funding R&D programmes • Subsidies for wind energy industry, association for wind energy • Support for local cooperatives for local experimentiona dn deployment Financing for grid connection, grid balancing

Table 19 shows the **main SI functions** observed in each of the cases. This shows that in all cases, the innovation system performs the function of knowledge development & diffusion, even though the primary audience may be different (end users, entrepreneurs, manufacturers, R&D actors, local communities, governmental actors). The innovation systems in Brazil and Denmark have narrower focus (bio-ethanol, wind energy), but carry out all (or almost all functions). In these cases, as well as for KCIC, the functions of entrepreneurial experimentation, market formation and resource mobilization are particularly well represented, given the importance of the private sector and market demand/supply as drivers. Market formation has also been important for BEE, creating demand and supply for EE products and services. Legitimation has been important for the adaptation cases in Haiti and Jakarta, for the necessary support for interventions with local communities. For India, Brazil and Denmark, this function focussed more on legitimation of technologies or processes, to create confidence for investors and buyers. The development of positive externalities is especially clear for bio-ethanol in Brazil and wind energy in Denmark, where reduction of national dependency on international (sugar, oil) markets coincides with the development of new business opportunities and sectors, as well as – in the case of Denmark – increased opportunities and energy access for rural communities. The function 'influence on direction of the search' can be fulfilled by a variety of actors and interventions, as the cases show: from national to local government and from international standards to local policy plans.

[619] Requiring oil & gas exploration companies exploring in Brazil to invest 1% of their gross revenue from these activities in R&D projects "to the interest of the national energy sector".

[620] the Brazilian National Development Bank, National Council for Scientific and Technological Development

4.2 Lessons learned and key success factors

While each case study involves a specific national and/or sectoral context, there are a number of broader observations that can be made in terms of good practices and lessons learned. Table 17 summarises some key characteristics and the focus, as well as the lessons learned of each of the cases. Table 18 organizes the case study-specific lessons learned into similar lessons – or lessons related to similar characteristics - across case studies. This is translated further into common success factors.

This comparative analysis leads to the following, more generalized lessons learned and good practices.

1. Take a systemic perspective towards the establishment/strengthening of the NSI, integrated with host country development objectives (all cases)…
   The build-up of an NSI needs to be aligned with the country's development priorities for legitimation and long-term support. Once climate policy goals have been defined in the context of national socio-economic objectives, the interactions between mitigation, adaptation and sustainable development become clear. Such a systemic perspective makes it possible to define with some specificity the strategic prioritization of sectors and overall innovation needs. At the same time, such a perspective also requires some long-term visioning and planning.

2. ... yet a tailored approach to bridging sector- and innovation phase-specific gaps (all cases)
   Notwithstanding the required systemic perspective (#1 above), a tailored approach to the development of an NSI is needed, given that innovation needs vary from sector to sector. This, in turn, requires a comprehensive understanding of gaps and barriers related to specific sectors and specific phases of the innovation cycle. Such an approach is underpinned by a systematic focus on innovation system functions that need to be addressed as well as the structural elements (actors, institutions, interactions, and infrastructure) that can help in specific sectors.

3. Leadership with a collaborative attitude and an understanding of local context: One common and significant feature of the case studies (particularly BEE, KCIC and Jakarta examples,) is the importance that initiatives are led by people and/or organizations with a broader and nuanced understanding of the local innovation system. This helps in engaging the right kind of actors, marshaling the right kind of resources, identifying and addressing the gaps in the innovation process, and tapping into the complementary structures and processes of the overall innovation system to advance the climate initiatives. If the capabilities and decision-making in a project are dominated by actors that are not locally grounded, such processes may stall. Specific organizations that are able to take the lead (e.g., BEE. KCIC) can play a key role as 'integrators' or 'coordinators' of the various structural and functional aspects of the innovation system. The overarching and interactive functioning of the leading organizations can facilitates not only coordination among actors but also addressing gaps such as financial resources, enabling policy frameworks, or human and institutional capacity.

4. Participation of, and interactions among, local actors facilitates innovation and alignment (all cases)
   Participation of, and interactions, among domestic actors (at the national and sub-national level) is key since they have the best understanding of local context and institutions, they often have the largest stake in the outcome, and therefore are best placed to help fill gaps in, and advance functions of, the innovation system. Therefore, promoting such interactions is critical, whether among knowledge institutions such as universities, between knowledge institutions, firms and government agencies, between firms and communities, among government agencies, etc. In the first-mover cases (Brazil, Denmark), networks between actor groups were key for moving the technology along the innovation cycle and the formation of markets. In the case of BEE, the Bureau drew upon existing networks, expanding them to facilitate the flow of knowledge (such as international best practices) as well implementation of programmes.

5. Engage with international institutions and collaborations to help build local institutions, networks (BEE, KCIC, Haiti DRR, Jakarta)
   International institutions can play an important role in strengthening NSIs by bringing in global best practices, assisting with development, adaptation and diffusion of new technologies, helping mobilize financial and technical resources, and building capabilities of local actors and institutions. But engagement with such institutions is likely to be most effective when based on an understanding of local innovation needs and gaps.

For KCIC, international actors combined forces with local actors to create the center and generate capabilities and knowledge, which was subsequently shared again internationally, amongst others in the network of CICs. Haiti benefitted strongly from the activities of the Sahana volunteer network, applying internationally developed tools and knowledge locally, which in turn improved multilateral agencies responses.

6. Ensure that innovation and organizations are evolutionary and able to adapt to new circumstances, through continuous monitoring and review (all cases)
   The innovation context, capabilities, and resources change over time and therefore so do innovation needs. At the same time, analysis of the functioning of the NSI may also yield insights as to how to strenegthen the NSI and make it more effective. As a result, innovation processes and institutions have to be able to adapt to the changed circumstances and emerging knowledge so as to remain relevant and effective. This may mean engaging with new actors or addressing new functions of the NSI, e.g. with different types of interventions. It may also mean that organizations themselves may evolve over time. This can be observed in first-mover cases but also in the other cases.

   Therefore, continuous monitoring and evaluation of innovation needs and outcomes, and the ability to adapt in in response, takes on great importance. The insights from such monitoring and review can be used to improve the setup and implementation of the NSI, thereby creating a dynamic situation where the NSI is able to evolve in response to the new knowledge and understanding. It can provide a better understanding of long-term policy goals to innovation actors, allowing for course correction, when and where needed.

7. Portfolio of solutions (all cases)
   The scale and complexity of climate change adaptation and mitigation challenges in the context of sustainable development as well as the diversity of a national system of innovation means that the intervention also cannot be singular. It requires a portfolio of measures to strengthen the relevant functions across the innovation cycle and to build capacity with a variety of actors. Different sectors, innovation cycle phases and actors will have different needs, benefitting from a range of tailor-made approaches, including a combination ofboth top-down and bottom-up approaches are used interactively and iteratively.

8. Deal with structural problems (Jakarta, Haïti DRR, Brazil)
   In some cases, the underlying problems of poverty, lack of influence and voice and environmental or social challenges are not acknowledged when designing the intervention, or only becoming clear during the intervention. Focussing on broader development goals, NSI functions and including all stakeholders usually addresses this, but structural problems may rebound. Even when solving them is beyond the capacity of a climate action project, attention for these structural problems needs to be part of an integrated approach.

Table 17 Summary of key lessons learned for each of the case studies

Case	Focus	Lessons learned

India BEE	• Mitigation
	  ○ energy demand
	• Top-down
	• Main IS functions:
	  ○ F1 Knowledge development & diffusion
	  ○ F2 Entrepreneurial experimentation
	  ○ F3 Market formation
	• International support received:
	  ○ Some of the initiatives tapped on international technical expertise, e.g., S&L Programme drew on the expertise of CLASP.
	  ○ Engagements with CLASP also facilitated funding opportunities with USEPA, USAID, etc.
	  ○ The standards used in the UJALA programme were devised by an international expert group.
		• A tailored approach is required as innovation needs vary
		• Bridging sector-specific gaps is key
		• Innovation activities need to be strategic, iterative and evolutionary
		• Coordination and integration of NSI elements is crucial
		• Strategic prioritization of focus sectors improves efficiency, credibility and legitimacy

Kenya CIC	• Mitigation & adaptation
	  ○ Energy, agriculture, water, waste management
	• Top-down
	• Main IS functions:
	  ○ F1 Knowledge development & diffusion
	  ○ F2 Entrepreneurial experimentation
	  ○ F3 Market formation
	  ○ F5 Resource mobilization
	• International support received:
	  ○ International support and collaborations (consortiums) to build local technical and innovation capacity, project management capacity, etc. For instance, CTCN is working with KCIC to help Kenyan SMEs adopt efficient technologies[621].
	  ○ International support to generate funds for R&D, innovation, projects
	  ○ International support to mobilise policy and market action to create an enabling setting for climate action
		• Organizations need to evolve and diversify with time to achieve the ultimate goals
		• Collaborative, multi-actor partnerships are crucial for effective climate action
		• Funding model design needs to be sector/innovation cycle phase-specific
		• Full integration with host country development objectives is needed for effective outcomes
		• Local actors' engagement in the design is crucial for effectiveness
		• Effective interaction among local actors is vital for peer learning
		• International institutions and collaborations can help build local institutions and networks

Haiti DRR	• Adaptation	• Taking a systemic perspective is important

[621] Oscar, Kevin. (2020). Businesses In East Africa Set To Benefit From New Programme. February 21. 2020. https://www.kenyacic.org/2020/02/innovation-in-design-3/

	○ Disaster Risk Reduction in all sectors • Top-down & bottom-up • Main IS functions: ○ F1 Knowledge development & diffusion ○ F4 Guidance of the search ○ F5 Resource mobilization ○ F6 Legitimation • International support received: ○ Technical cooperation and capacity building for elaborating the national plan from e.g, UNEP ○ Funding from bilateral donors for educational and training programmes ○ Financial support for disaster recovery from multi/bilateral institutions, including CCRIF ○ Contribution from volunteers, e.g, Sahana	• Local knowledge and needs need to be taken on board • Strong networks are crucial in coordination • Combined top-down and bottom-up efforts can create synergies • Multi-stakeholder partnerships, including international collaboration is important • Systemic change requires time • Long-term planning and continuous review are important
Brazil bio-ethanol	• Mitigation ○ Transport (Energy/Agriculture) • Top-down & bottom-up • Main IS functions: ○ F1 Knowledge development and diffusion ○ F2 Entrepreneurial experimentation ○ F3 Market formation ○ F5 Resource mobilization ○ F6 Legitimation ○ F7 Development of positive externalities • International support received: not applicable, although international developments resulted in economic opportunities by creating international markets	• For successful innovation, both technology-push and technology-pull policies are needed • Innovation policies and coordination are needed across the value-chain • A mix of bottom-up and top-down measures facilitate innovation • Coordination between knowledge producers and users accelerated diffusion • Aligning technological development to societal goals facilitates formation of coalitions that provide political support and legitimacy • Innovation takes time, is uncertain, and highly dynamic • International aspects can influence the development of local innovation systems, intentionally or not. • Local support for technology innovation and early market formation increased the country's ability to compete in international markets • Capabilities are needed across all stakeholders Multi-stakeholder partnerships, including international collaboration is important
Jakarta urban flood manage-ment	• Adaptation ○ Urban flood management • Top-down and bottom-up • Main IS functions: ○ F1 Knowledge development and diffusion ○ F5 Resource mobilization • International support received:	• Integrated and collaborative governance is crucial • Complex problems require a portfolio of strategies • Focus on chronic problems and root causes is essential • Adaptive governance and continuous learning are crucial • Building capacities of local governments and agencies is important • Future risk assessment and long-term planning is indispensable • Convergence of DRR, climate change adaptation and development processes is crucial

	○ Support/collaborations for scientific studies on vulnerability & risk assessments, potential solutions ○ Capacity building, awareness generation, knowledge diffusion and projects ○ Building project consortia/public private partnerships to create investment opportunities for various stakeholders ○ Funds for R&D, innovation, projects, etc.	• Risk governance needs to go beyond technical strategies, requiring a people-centered approach • Community preparedness is key • Context specificity of knowledge has implications for knowledge- and technology-transfer outcomes • Engaging local communities in developing EWSs increases capacity to respond during emergencies
Denmark wind energy	• Mitigation ○ Energy supply • Top-down & bottom-up • Main IS functions: ○ F1 Knowledge development and diffusion ○ F2 Entrepreneurial experi-mentation ○ F3 Market formation ○ F4 Guidance of the search ○ F5 Resource mobilization ○ F6 Legitimation ○ F7 Development of positive externalities • Interational support received: not applicable, although international markets resulted in economic opportunities by creating international markets	• For successful innovation, both technology-push and demand-pull policies are needed. • A dynamic interaction and synergy between bottom-up and top-down measures facilitates innovation • Coordination between knowledge producers and knowledge users accelerates technology development and diffusion • Multi-stakeholder partnerships, including international collaboration is important • Aligning technological development to societal goals can facilitate formation of coalitions that provide political support and legitimacy • Participatory approaches increase ownership and public acceptance • International aspects can influence the development of local innovation systems, intentionally or not • Local support for technology innovation as well as early market formation increased the country's ability to compete in international markets

Table 18 Comparison of lessons across case studies

Type of lesson learned	**India BEE**	**Kenya CIC**	**Haiti DRR**	**Brazil bio-ethanol**	**Jakarta urban flood management**	**Denmark wind energy**
Systemic and strategic perspective	• Strategic priority-zation of focus sectors improves efficiency, credi-bility, legitimacy • Coordination and integration of NSI elements is crucial	Full integration with host country develop-ment objectives needed for effective outcomes	Taking a systemic perspective and long-term planning are important	• Innovation policies and coordination across value chain needed • Aligning with societal goals	• Convergence of DRR, adaptation, development pro-cesses is crucial • Future risk assess-ment and long-term planning is indispensable	Synergies between innovation policy and other societal goals was important
… yet tailored to specific	• Tailored approach	Funding model design needs to be		• International coope-ration in innovation,	Context-specificity has implications for	Sustained government and public support can provide

sector and innovation phase	is required as innovation needs vary across sectors • Bridging sector-specific gaps is key	sector/innovation cycle phase-specific		technology transfer was crucial in all phases of development	knowledge and technology transfer outcomes	legitimation, altering (institutional) risk perceptions of a technology
Leadership: All relevant actors involved in a coordinated and collaborative way	Coordination and integration of NSI elements is crucial	Collaborative, multi-actor partnerships are crucial for effective climate action	Multi-stakeholder partnerships, incl. international collaboration, is important	• Coordination between knowledge producers & users are important, as are multi-stakeholder partnerships • Capabilities important for all actors	• Integrated and collaborative governance is crucial • People-centered approach is necessary	Coordination between knowledge producers & users are important, as ares multi-stakeholder partnerships
Local knowledge and capacity is key and local actor networks need building	A tailored approach is required as innovation needs vary	• Collaborative, multi-actor partnerships are crucial for effective climate action • Effective interaction among local actors and across value chains is vital for peer learning Local actors' engagement at the design stage is crucial for effectiveness	• Strong networks are crucial for effective disaster risk management and reduction Local knowledge and needs need to be taken on board	• Formation of coalitions provided political support and legitimacy • International networks and learning was important for for all actors groups • Local support for technology innovation and early market formation increased ability to compete in international markets	• Building capacities of local governments and agencies is important • Community preparedness is key	• Formation of coalitions provided political support and legitimacy • Local support for technology innovation, early market formation increased ability to compete in international markets Participatory approaches increase ownership & public acceptance
International cooperation can have value in multiple ways		International institutions and collaborations can help build local institutions and networks	Multi-stakeholder partnerships, including international collaboration is important	• International aspects can influence development of local innovation systems • International cooperation in technology innovation, transfer crucial in all phases of development		• International aspects can influence the development of local innovation systems, intentionally or not • Multi-stakeholder partnerships are important • Leverage international developments
Dynamic innovation	Innovation activities need to be strategic,	• Organizations need to evolve and diversify	• Long-term	• Innovation processes take time is uncertain,	Adaptive governance and	• Dynamic interaction, synergy between bottom-up/

requires flexibility & adaptivity, and monitoring	iterative and evolutionary	with time to achieve the ultimate goals • Funding model design needs to be innovation cycle phase-specific	planning, continuous review are important • Systemic change requires time	and highly dynamic • Monitoring is important	continuous learning are crucial	top-down measures facilitates innovation • Ensure monitoring so learning can take place • Dynamic, evolving innovation systems continuously utilize, create opportunities
Portfolio of solutions	Different approaches for different sectors	Funding model design needs to be sector/ innovation cycle phase-specific	Combined top-down/bottom-up approaches can create synergies	Both technology-push and technologyl-pull policies are needed, as well as bottom-up and top-down measures	Complex problems require a portfolio of solutions and policy responses	Both technology push and demand pull policies are needed, as well as bottom-up and top-down measures
Deal with structural problems	• Focus on EE addressed key issue of energy security • Activities addressed lack of supply/ demand for EE solutions	Focus on agriculture and water addressed key issues in main sectors of economy	Increasing focus on disaster preparedness, rather than disaster response, incl. resilient buildings, preparedness strategies, insurance	• Addressing dependency on international markets (sugar, oil) • Aligning technological development with societal goals facilitates coalition forming, support and legitimacy to new technology	Focus on chronic problems and root causes is essential Increasing focus on structural prevention, rather than disaster response	Addressing dependency on international markets (oil), improving local opportunities in rural areas

5 Conclusions & recommendations

The case studies covered in this compilation illustrate and underline the value of taking a systematic approach to strengthening relevant parts of national systems of innovation that can then support and advance climate action through scaled up development and diffusion of climate technology for both adaptation and mitigation.

The framework presented in Section 2.3 (Tables 3-5) highlights the functions an effective NSI needs to entail, the kinds of resources required to support those functions, and the structural elements that might need attention to allow fulfilment of the functions. The NSI functions and the structure-function framework outlined can serve to guide the systematic approach to implement the NSIs to advance climate action.

This framework also indicates that the specific nature of the functions, resources, and structural elements required will vary from sector to sector, as illustrated clearly by the case studies. This emphasizes that rather than try to strengthen the NSI in the abstract, it makes sense to focus efforts at enabling specific climate actions, also depending on the stage in the innovation cycle in which the climate action takes place. In other words, if the climate action is, for example, energy-efficiency-related, then the NSI may need to be strengthened in a different way than when the action is e.g. related to renewable energy supply. This is not to say that efforts at strengthening the NSI more generally are not useful. They are, as noted below, but since what is needed to support climate innovation and action is quite sector-specific, suitably targeted efforts are necessary, in fact, critical.

This then leads to another point highlighted by the case studies. If the requirements of the NSI are sector-specific, then a prioritization of focus sectors has to be the first step in developing or strengthening an NSI. As the BEE case highlights, the initial focal areas were chosen after careful deliberation, taking into account the local context. The KCIC also took a similar approach of prioritizing specific areas in the broad context of climate innovation. The Denmark wind energy and Brazil bio-ethanol cases show that for first movers, deliberate choices had to be made to focus on these sectors. And the actions highlighted in the Haiti and Jakarta cases were driven by an understanding of the need to strengthen – and broaden beyond – disaster response. In all these cases, the upfront identification of priorities guided the actions required to support relevant elements of the NSI.

Once the priorities are identified, mapping the NSI before designing and implementing specific strategies helps create the needed understanding of the state of the functions, structural elements, and resources of the innovation system. This can help identify gaps in the innovation ecosystem that need to be addressed and that, in turn, makes it possible to identify strategies to fill these gaps. This may involve strengthening and emphasizing functions of the innovation ecosystem such as market creation and resource mobilization. It may also involve strengthening actor networks and coordination, as all the cases highlight, including linkages among local actors, between local and international actors, and between researchers and entrepreneurs. Building synergies with local policies and priorities greatly supports the legitimation function.

The role of local knowledge in guiding these actions cannot be over-emphasized since successful actions all require a thorough understanding of the local context and needs. At the same time, international collaboration too may be particularly useful, not only for knowledge development and diffusion, but also in as well as harnessing financial and technical resources and building capabilities of local actors. Another clear conclusion from the case studies is the importance of learning from experiences and using that learning to continuously improve efforts intended to strengthen various elements of the NSI, especially in relation to evolving context.

Another common, vital feature of several of the case studies is that the top-down initiatives are led or managed by organizations with a holistic understanding of the local innovation system. Since the leading organizations are conversant with the structural and functional aspects of the overall innovation system, they are adequately placed to evaluate the available capabilities, identify missing links, and develop the necessary resources at the right stages of the innovation cycle. They are also suitably positioned to draw on the complementary resources frameworks of the larger innovation set-up in the country.

One last point is implicit in the case studies: efforts to advance climate action eventually are embedded in the local context and draw upon local resources. Therefore, strengthening local actors such as universities and local

government, deepening linkages between such knowledge entities, private actors and government agencies, and building a culture of experimentation and learning will serve to strengthen the NSI more broadly and therefore also facilitate climate action in specific sectors. International cooperation can be used to strengthen this.

Based on the above, the overall recommendation from this analysis, drawing on the case studies, is that a systematic approach be undertaken to implement the NSI to advance climate action, using the NSI functions and the structure-function frameworks as the overarching guide. This approach should help ensure that the NSI is performing the relevant functions, which may require strengthening of NSI functions, marshalling of resources, and addressing weaknesses/gaps in structural elements in NSIs. But as these are specific to sectors, it is recommended the above builds on an initial identification of sectoral priorities, aligned with national policy goals and socio-economic objectives.

Good practices for potential replication that have been identified in the various case studies lead to the following specific recommendations. Here, we make a distinction between the preparation for actions to align the NSI with climate action, recommendations to design and implement efforts to strengthen the NSI's contribution to climate action, and monitoring/evaluation/revision of the NSI's contribution to climate action. This is done, however, with the understanding that the boundaries between these phases is not strict.

Preparation recommendations

⇒ *Develop climate-action plan in alignment with long-term policy framework and socio-economic priorities:* It is essential to ensure that climate actions are in synergy with the overall policy framework of the country and that it facilitates the country's overall development and climate objectives. This has two benefits:
1. It allows for clear articulation of priority areas/sectors, which will help efforts to suitably strengthen the NSI; and
2. Synergies with local objectives (such as livelihoods, gender parity) will also help enhance buy-in and participation by stakeholders.

⇒ *Map the NSI before designing and implementing strategies:* Such mapping helps create the needed understanding of the existing structural elements and functions of the innovation system, barriers and missing links in the innovation ecosystem, crucial actor groups, state of resources and capabilities, potential synergies and trade-offs between other initiatives and policy structures, and the role of international collaborations. This knowledge can inform and guide subsequent efforts to strengthen the NSI and make them more effective.

⇒ *Look for win-win measures:* It is important to design win-win strategies (through, for example, an appropriate choice of focus area, innovative governance and market models) to ensure participation and acceptance by all relevant stakeholders and minimization of risk factors. *Engage both public and private sectors: E*nsure the participation of diverse stakeholders to address the complexities and uncertainties associated with innovation processes. This will also help in tapping into the capabilities and skill sets of a range of actors.Here it is important to note that the above are crucial in the preparatory phase, but that it is important that they continue to be applied during the implementation phase.

Design and implementation recommendations

⇒ *Establish a clear role for a coordinating agency*: In situations where diverse stakeholders need to come together to make an intervention/innovation effective, the role of coordinating agencies or 'system operators/integrators' becomes important. Coordinating agencies with a holistic understanding of the strengths and shortcomings of the NSI can organize and coordinate the actions of different stakeholders, tap into resources and strengths of various actors, and address other system gaps to maximize impact.

⇒ *Explore innovative, customized, and flexible funding frameworks*: Explore funding models to suit the stage, scope, and risk perception of the innovators/firms. Complement funding schemes with enabling policy and financial regimes for effective and sustained outcomes.

⇒ *Put together a suitable mix of actors and policies*: to accommodate the wide range of actors and innovation phases, a mix of policies is needed, providing both technology push and technology pull type incentives, and engaging both bottom-up and top-down actors.

⇒ *Allow flexibility in how policy goals are met*: This is particularly relevant in a developing country context. Where possible, the policy goals and aspirations should be defined, with the stakeholders given the flexibility to adopt the technology/means that suit them best to achieve those goals (e.g. be technology-neutral). This will generate credibility for policy implementation, manage risk perceptions of stakeholders, and facilitate faster attainment of policy goals.

⇒ *Pay attention to market creation for climate technologies*: For a mature and effective ecosystem for green innovation, policies, market structures, and actor capabilities should be directed towards creating sustained demand and supply dynamics for clean technologies.

⇒ *Focus beyond hardware innovation:* Technological hardware can have an important contribution to mitigation and adaptation goals. However, this should be combined with building the capacity of local actors, creating the right communication channels for sharing knowledge and informa-tion, and establishing the right regulatory framework for an effective strategy to scale up imple-mentation of climate technology.

⇒ *Strengthen local capabilities, while ensuring coordination:* Strengthening local capabilities is crucial for effective action. However, there is also a need for harmonization of curricula, protocols and information management mechanisms. Finding the right balance between bottom-up and top-down processes can be challenging, but can contribute to more effective strategies.

⇒ *Create complementary knowledge and servicing infrastructure*: In order to promote and implement technological innovations effectively and consistently (in the long term), the creation and retention of complementary knowledge, skill sets, and a trained human resource base must be facilitated. This will also aid in monitoring, evaluating, and upgrading technological innovations.

⇒ *Maximize productive engagement with international actors and opportunities*: International partnerships and exchanges can be very useful in learning from others' experiences and best practices. They also can help develop local technological, financial, political, and human resources. Therefore international engagement can help strengthen the NSI in many different ways but that also requires local actors actively shaping and driving this engagement. Furthermore, the international arena may well offer market opportunities that could be very productive.

Monitoring, evaluation, learning and revision recommendations

⇒ *Ensure there is adequate and systematic monitoring, evaluation and revision:* Since systemic change requires time, short-term planning (with too short time frames covering only a few years) will only be effective to a limited degree in achieving objectives. It is therefore important to plan according to longer time frames, while continuously taking account progress made, and reviews where necessary.

⇒ *Evolve and improve through learning by doing and learning through analysis*: Learning comes both from evaluation and review-based analysis as well as experinetial learning by doing. These are complementary forms of learning and both should be utilized as the basis for constant enhance-ment of the NSI through the strengthening of functions and structural elements.

⇒ *Adapt to evolving context and needs:* Climate actions will be ongoing activities, and the social, economic, and political context and needs likely will evolve over time. Therefore, NSI actors and institutions will also need to adapt and evolve over time in line with these changes. This responsiveness and dynamism has to be part of the institional design from the early stages so the NSI continues to be relevant and useful in helping deliver successful climate action over time.

Most of these recommendations will be operationalized through the appropriate government entities that are tasked with planning, implementing, or monitoring and evaluating. But many are also relevant for **other audiences**. Multi- and bilateral organizations can use them in the design of their support activities for national governments and other stakeholders. Civil society organizations, citizens and communities can use them to strengthen their public engagement activities, particularly during the preparatory stages to ensure that the prioiritization is robust. They often also have knowledge to offer. The private sector is a critical stakeholder, although their role varies by issue at hand, for instance between adaptation and mitigation. Their engagement is important in the preparatory, design and implementation phases. Therefore many of the recommendations directly pertain to them, such as those relating to entrepreneurial ooportunities, how to address barriers for development and deployment of their technologies, routes for successful ways to engage with local partners

and stakeholders, and the importance of using appropriate impact assessment, forecsting and risk management tools. And lastly, academic/research can use the lessons to help direct their research and educational activities to increase their relevance and effectiveness. They can potentially also play a role in the evaluation phase mentioned above.

Annex 1: Main NSI functions performed across case studies

Table 19 Main NSI functions performed in each of the cases, shading indicates the more important functions, as summarized at the start of each case study

Case	F1 Knowledge development & diffusion	F2 Entrepreneurial experimentation	F3 Market formation	F4 Influence on direction of search	F5 Resource mobilization	F6 Legitimation	F7 Development of positive externalities
India BEE	• Awareness-building programmes to create an informed user base for EE • Interactions facilitated by BEE to promote knowledge diffusion, peer-to-peer learning, best practice promotion • Knowledge exchange platforms • System to monitor, evaluate, adapt set-up	• Technology-neutral nature of programme for flexibility for entrepeneurs • Evolutionary approach to promote experimentation • Innovative funding designs based on stakeholder capabilities to de-risk investments	• Awareness raising to create demand for EE • Innovative business models to incentivize actors, sustain demand • Phased approach, PPPs to support market transformation • Actor exchanges to create competition • Energy manager, verifier capabilities, protocols/ standards to create trust in market • Pilot programmes for early market development	• Technology-neutral nature of programme for flexibility for manufacturer to innovate • Interaction among industry actors to spread best practices, steer innovation/ R&D • Definition of energy saving targets to promote innovation, R&D	• Ensured market demand, regulatory obligations to encourage manufactures to invest • Innovative funding models (PoAs, ECerts, demand aggregation, auction mechanisms) to mobilze resources	• Evolutionary approach, increasing ambition over time • Flexibility for industry to meet targets (credits, ECerts) • Start with low-hanging fruit to show feasibility • Creation of labels, testing infrastructure • Ensuring market demand	• Development of local manufacturing eco-systems • Development of institutional infrastructure for effective implementtation • Flexibility for manufacturers to meet targets • Interactions resulting in trust to enable implementation, scaling up • Incentives increasing actors' motivation • Increased human capabilities
Kenya KCIC	• Training, capacity building, mentorships for entrepreneurs • Funding innovation, diffusion of clean tech • R&D collaboration, knowledge sharing networks & events • Access to R&D facilities, incubator hubs • Market intelligence, policy advice to business	• Innovative engagement/ business models/funding mechanisms for different stakeholders, innovation cycle phases • Facilitation of interactions to promote development of green businesses and uptake of projects • Policy advocacy to promote uptake and implementation of green business projects • Physical infrastructure for actor engagements	• Capacity building of actors to engage in the market • Creation of awareness of merits of technologies, developing market demand • Funding for green projects in different phases, developing market supply side • Risk management to encourage business participation • Policy advocacy to promote market creation,reduce risk • Creation of market infrastructure (skills,	• Recognition of priority sectors for support and funding • Support/funds businesses / innovations aligned with overall policy goals • Advocacy for enabling policy for green RD&D • Facilitation of interactions between actors to guide the direction of research, learn from best practices	• Use of different business models/ funding models and management of risks across the innovation cycle • Builds actors'fund-raising capacities • Connecting potential funders/ project developers • Government engagement to facilitate	• Due diligence on clients, investors, collaborators • Engaged in mainstreaming SDGs, climate change • Mediating discussions between actors to enhance credibility of project/ process	• Capacity building to implement projects, fundraise, negotiate with collaborators, procure technologies • Development of networks, institutions, and infrastructures for R&D, innovation, enhancement of value chains • Establishment of pro green business environment

			funding mechanisms, facilities)				
Haiti tillsDRR	• Committee to coordinate awareness-raising campaigns • Communication campaigns by government, NGOs • Network of local DR committees to develop/share knowledge, data, build capacity • Platforms, mechanisms for institutional/ intersectoral coordination • National databases, data tools, data gathering by many actors • Training, courses	• Adaptation of Sahana Open source software to local context • Use of Sahana by volunteers and local actors to create new databases, consolidating DRR data management		• National system for coordination of DR management SNGRD • Strengthened networks (government, teaching, communities) to provide plans, guidance, protocols • Plans, guidance, protocols, improved information provision re geospatial data to influence building practices, more resilient infrastructure • Improved coordination under several thematic committees	• Funding from government, international donors, crowdsourcing • human resources (volunteers) for disaster response, tool/knowledge development • Dedicated budget lines for emergency response/ preparedness, tax revenues • Development of disaster rediction finance strategy • Participation in regional insurance mechanisms	• Integration of dRR in strategic documents • Sectoral committees to develop standards, codes • Codes and protocols for more resilient infrastructure • Guidelines for interaction, communication in case of a natural disaster	
Brazil bio-ethanol	• Multiple RD&D projects conducted via multi-stakeholder collaborations, including producers and users across the value chain	• Experimentation initially led by sugarcane producers, then by other private sector actors such as technology suppliers • Policies to incentivize experimentation, incl	• Policies to stimulate demand, including public procurement • Government coordinating with sugar, car, oil&gas industries to align expectations to create trust in	• Presence of a strong sugarcane industry, industry lobby • Policies, institutions aligned expectations for future ethanol technology (and market)	• Government subsidies, R&D funding from research and innovation public funds, national development bank	• Sugarcane producers supporting ethanol to reduce dependency on international markets	• Recognising ethanol as industry of national interest, creating opportunities for industrial development

	• Policies to promote knowledge development, diffusion • ANP requirement to use 1% of oil&gas revenues for R&D • Local industry llearning from imported technology	status as 'industry of national interest' • Collaborations with university, government on early experimentation • Multi-stakeholder collaborations for exchange between knowledge producers/ users, accelerating incorporation of lessons learned	the market and coordinate action for ramping up • Automobile industries developing Flex-Fuel Vehicles • Increased international environmental concerns, resulting in demand for sustainable biofuels	development, including standards, regulations • Designation of ethanol industry as 'industry of national interest' • International agreements, policies to reprioritize between E1GE2G	• ANP requirement to use 1% of oil&gas revenues for R&D • Private funding via private R&D institutes, technology suppliers, manufacturers and joint R&D projects with universities, government	• Early mandatory blending requirements for ethanol • Recognition of ethanol as industry of national interest • Public campaigns on ethanol vehicles to increase acceptance • Scientific meetings to share best practice • Benefits from reduced dependency on international markets	• Economic benefits for sugarcane, car, energy sectors • Job creation • Economic efficiency for consumers from FFV flexibility to choose fuel • Technological routes with lower environmenttal impact • Benefots leading to support for technology, policies
Jakarta urban flood management	• Subsidies, surveys to understand/assess causes, risks, impacts & potential solutions for floods • Flood forecast studies • Capacity building, awareness-raising programmes to develop capabilities of stakeholders, communities	• Project partnerships formed in consideration of required resources, skills for specific projects • Public private partnerships in large investment projects • Competitive tendering to select project participants in large scale projects	• Government authorities and agencies active participants to create an enabling setting for investments	• National, regional legislations steered search • Interactions with international innovation system/expertise also a key driver	• Internal partnerships, collaboration to generate funds • Public-private partnerships to address funding gaps	• Capacity, awareness building activities, stakeholder consultations to build trust, transparency, and ownership • Engagement of local communities in developing and implementing EWS	• Interactional partnerships for new resources, knowledge, technologies • Development of more aware, capable stakeholders incl youth • Capabilities,infrastructure for flood management with spill-over effects for other sectors
Denmark wind energy	• R&D funding lines, promoting knowledge development at universities • MSc, PhD, technical education programmes to develop wind energy capabilities • Individual scientists difused knowledge in rural areas	• Champions with a key role in early bottom-up experimentation; • Rural companies promoted experimentation with manufacturing process, learning "on the go". • Early rural experimenttation to form a wind TIS	• Strong government role to set conditions for a competitive market position for wind energy • Policies to reduce barriers (grid access, integration) and generate funds for wind energy RD&D and deployment (taxes) and incentives for wind turbine	• Societal resistance to e.g. nuclear energy to meet energy/ environmental goals • GovernmentR&D funding, especially for large-scale wind energy • Local cooperatives, small manufacturers, scientists in a community-owned,	• Energy/ environmental taxes to fund wind energy R&D • Consumers contribution to TIS through energy taxes, PSOs • University-industry interaction to fund R&D where public funding is limited	• Independent experts, environmenttalists viewing wind as alternative to nuclear, fossil fuels • Wind energy as key in national energy plans'. i.e. as a legitimate energy supply technology	• Financial support for local cooperatives, strengthening their capabilities and roles • Strong community ownership to ensure wind energy helps meet local community goals • Actors, networks with environmental and riural development

	• University-industry feedback between knowledge producers and users, diffusing knowledge among actors • Planning procedure, public hearings diffusing knowledge at different levels and local communities	with strong community ownership	manufactures, local cooperatives, end users, • Leveraging the inter-national market for the wind power industry in Denmark	small-scale system for rural development • International agreements, national energy plans' long-term wind energy targets to align expecta-tions around the techno-logy as a solution for existing challenges • Publications, meetings to set standards, share best practice for wind energy	• Multistakeholder partnerships e.g. to reducing risks for private companies • Feed-in-tariff, sub-sidies for building, operating wind parks, replacing aging turbines	• Publications highl-ighting Danish wind technology's good performance. • Local actors, coope-ratives increasing awareness re bene-fits for rural areas • Effective ublic hearings to ensure meaningful stake-holder engagement	concerns increasing political support for wind energy • Formation of a local RE system. reducing energy dependency and decarbonizing electricity production without nuclear power • Establishment of an internationally leading industry

Acronyms

For case or country-specific acronyms, the country is indicated in parentheses

ABBI	Brazilian Association for Industrial Biotechnology (Brazil)
AC	Air Conditioner
AI	Artificial Intelligence
ANP	National Petroleum Agency (Brazil)
AWLR	Automatic Water Level Recorders
AWS	Automatic Weather Systems
Bappenas	National Development Planning Agency (Indonesia)
BATAN	National Nuclear Energy Agency of Indonesia (Indonesia)
BNPB	National Disaster Management Agency (Indonesia)
BPBD	Regional Disaster Management Agency (Indonesia)
BPPT	Agency for the Assessment and Application of Technology (Indonesia)
BEE	Bureau of Energy Efficiency (India)
BIS	Bureau of Indian Standards (India)
BNDES	Brazilian National Development Bank (Brazil)
BNPB	National Disaster Management Agency (Indonesia)
BRIN	National Research and Innovation Agency (Indonesia)
CBIOs	Decarbonisation Credits (Brazil)
CCA	Climate Change Adaptation
CCRIF	Caribbean Catastrophe Risk Insurance Facility (Haiti)
CDM	Clean Development Mechanism
CDEMA	Caribbean Disaster Emergency Management Agency (Haiti)
CFl	Compact Fluorescent Lamps
CGEE	Centre for Strategic Studies (Brazil)
CIC	Climate Innovation Centre (Kenya)
CLASP	Collaborative Labelling and Appliance Standards Program (India)
CNAL	National Alcohol Commission (Brazil)
CNEP	National Council of Energy Policy (Brazil)
CNP	National Petroleum Council (Brazil)
CODETEC	Technology Development Company (Brazil)
CTBE	National Laboratory of Science and Technology of Bioethanol (Brazil)
CTC	Sugarcane Technology Center (Brazil)
CTESP	Thematic Committee for Education and Public Awareness (Haiti)
CTP	World Bank infoDev's Climate Technology Program
DANIDA	Danish International Development Agency
DEA	Danish Energy Agency (Denmark)
DFID	UK Department for International Development
DGWR	Directorate-General for Water Resources, Ministry of Public Works (Indonesia)
DGCK	Directorate-General for Human Settlements, Ministry of Public Works (Indonesia)
DISCOMS	Electricity Distribution Companies (India)
DKI	Special Region (Indonesia)
DML	Disaster Management Law (Indonesia)
DPC	Directorate for Civil Protection (Haiti)
DRF	Disaster Risk Financing
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSDA	Jakarta Water Resource Service (Indonesia)
DTU	Technical University Denmark (Denmark)
DVES	Danish Wind Electricity Company (Denmark)
DWS	Disaster Warning System
E1G	First generation bio-ethanol fuel
E2G	Second generation bio-ethanol fuel

EC	Energy Conservation
ECBC	Energy Conservation Building Code
EECP	European Cluster Cooperation Platform
EE	Energy Efficiency
EESL	Energy Efficiency Services Limited
EFSM	Early-Stage Finance Mechanism (Kenya)
EOC	Emergency Operations Centers
ESCerts	Tradable energy saving certificates
ESCO	Energy Service Company
EUDP	Energy Technology Development and Demonstration Programme (Denmark)
ESR	EU Effort Sharing Regulation
EU ETS	EU Emissions Trading System
EWS	Early Warning Systems
FAO	United Nations Food and Agricultural Organization
FAPESP	São Paulo Research Foundation (Brazil)
FFV	Flex-Fuel Vehicle
FINEP	innovation funding agency (Brazil)
FiT	Feed-in Tariff
GACI	International Cooperation Support Group (Haiti)
GHG	Greenhouse Gas
GIS	Global Innovation System
GOI	Government of India
GrEYAP	Green Economy Youth Activation Programme (Kenya)
HDI	UNDP's Human Development Index
HEI	Higher Education Institutions (Indonesia)
HSDP	Haiti Strategic Development Plan (Haiti)
IAA	Sugar and Alcohol Institute (Brazil)
IAC	Agronomic Institute in Campinas (Brazil)
IFD	Innovation Fund Denmark (Denmark)
IFRC	International Federation of Red Cross and Red Crescent Societies
INR	Indian Rupia
INT	National Technology Institute (Brazil)
IoT	Internet of Things
JEDI	Jakarta Emergency Dredging Initiative (Indonesia)
JUFMP	Jakarta Urgent Flood Management project (Indonesia)
KCIC	Kenya Climate Innovation Centre
KCV	Kenya Climate Ventures (Kenya)
KENIA	Kenya Innovation Agency (Kenya)
KLHJ	Ministry of Environment and Forestry (Indonesia)
LAPAN	National Institute of Aeronautics and Space (Indonesia)
LARAP	Land Acquisition and Resettlement Actions Plan (Indonesia)
LIPI	Indonesian Institute of Sciences (Indonesia)
MICT	Ministry of the Interior and Territorial Communities (Haiti)
MoE	Ministry of Energy (Denmark)
MOECRT	Ministry of Education, Culture, Research, and Technology (Indonesia)
MOHA	Minister of Home Affairs (Jakarta, Indonesia)
MoU	Memorandum of Understanding
MTEE	Market Transformation for Energy Efficiency (India)
MTP	Medium Term Plan (Kenya)
NAE	President's Committee for Strategic Issues (Brazil)
NACOSTI	National Commission for Science Technology and Innovation (Kenya)
NAPCC	National Action Plan on Climate Change (India)
NAP-DRR	National Action Plan for Disaster Risk Reduction (Indonesia)
NCCAP	National Climate Change Action Plan (Kenya)
NCICD	National Capital Integrated Coastal Development master plan (Indonesia)
NDC	Nationally Determined Contribution
NDMA	National Disaster Management Agency (Indonesia)

NEEA	Energy-Environmental Efficiency Rating (Brazil)
NGO	Non-Governmental Organization
NMEEE	National Mission on Enhanced Energy Efficiency (India)
NRF	National Research Fund (Kenya)
NSI	National System of Innovation
O&M	Operation & Maintenance
PAISS	Agricultural Joint Action Plan (Brazil)
PAT	Perform, Achieve, Trade programme (India)
PNGRD	Plan National de Gestion des Risques et des Désastres (Haiti)
PNI	National Incubator Policy (Brazil)
PoA	Programme of Activity under the CDM
PPP	Public-Private Partnerships
PSDH	Strategic Development Plan of Haiti (Haiti)
PSO	Public Service Obligation (Denmark)
R&D	Research & Development
RIDESA	Interuniversity Network for the Development of the Sugarcane Industry (Brazil)
RISTEK	Ministry of Research and Technology (Indonesia),
ROSHANEE	Roadmap of Sustainable and Holistic Approach to National Energy Efficiency (India)
RPJMN	Medium-Term National Development Plan (Indonesia)
RPJPN	Long-Term National Development Plan (Indonesia)
SADC	Swedish Agency for Development and Cooperation
SDGs	UN Sustainable Development Goals
SERC	Strathmore Energy Research Centre (Kenya)
SIDS	Small Island Developing States
SIT	Secretariat for Industrial Technologies (Brazil)
S&L	Standards and Labelling programme
SME	Small and Medium-size Enterprises
SNGRD	Système National de Gestion des Risques et des Désastres (Haiti)
SOR	Sahana's Organization Registry (Haiti)
SPC	Segregated Portfolio Company (Haiti)
SSI	Sectoral System of Innovation
STI	Science, Technology and Innovation
STP	Science and Technology Parks
TEC	Technology Executive Committee
PITE	Technology Innovation Partnership Programme (Brazil)
TIS	Technology Innovation System
UFRJ	Federal University of Rio de Janeiro (Brazil)
UN	United Nations
UNB	University of Brasilia (Brazil)
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICA	Brazilian Sugarcane Industry Association (Brazil)
UNICAMP	State University of Campinas (Brazil)
UNIDO	United Nations Industrial Development Organization
US AID	United States Agency for International Development
US EPA	United States Environmental Protection Agency

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References