The Barriers to Deployment of Renewable Energy: Application of Sequential Decision-Making and Derisking Models in Emerging Markets and Developing Economies

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Dedication

"Education is the most powerful weapon which you can use to change the world"

"It always seems impossible until it's done."

Nelson Rolihlahla Mandela

This PhD thesis is dedicated to my late father José Luis Alfaro Musa, a petrochemical engineer, and my mother Filomena Pelico Bokara, a medical nurse.

They nurtured in me the passion to lead in the interdisciplinary sustainability space and provided me with the means and values to figure out ways of healing the planet while putting people left behind from the global energy transition first.

Their education and dedication led me to pursue university studies in Madrid (Spain), London and Lancaster (UK) in business with focus on finance; economics with focus on natural resources, emerging markets and developing economies; and engineering with focus on renewable energy and its environmental, social and governance dimensions.

After finalizing school in Malabo (Equatorial Guinea), and graduating in petrochemical engineering abroad, my father's first project was a small-scale hydropower plant in his native Bioko Island, while my mother graduated in nursing in Madrid (Spain). My MSc dissertation on the impact of oil in Equatorial Guinea was my initial attempt to use different disciplines to cure "Dutch Disease".

Declaration

This thesis has not been submitted in support of an application for another degree elsewhere, does not exceed the permitted maximum word length of 80,000 words, it is the result of my own work and includes nothing that is the outcome of work done in collaboration, except where specifically indicated.

Raúl Iván Alfaro Pelico, 30th September 2024

Many ideas of the thesis were the product of my own research contributions, and from discussions with my PhD supervisor Prof. George Aggidis and co-supervisor Dr. David Howard on their own research (below listed chronologically):

1. *Alfaro-Pelico, R.I. (2000) The Impact of Oil in the Economy of Equatorial Guinea: Theory, Evidence and Limitations of the Dutch Disease Model, MSc degree award in Economics dissertation submitted to SOAS, University of London (UK).*

2. *Aggidis, G.A.; Howard, D.; et al. (2006) Maximising the benefits of Hydropower by developing the North-West England Hydro Resource Model. HYDRO 2006, Porto Carras (Greece), 25-28 September 2006.*

3. *Aggidis, G.A.; Howard, D. et al (2007) Renewable Energy Resources Impact on Clean Electrical Power by developing the North-West England Hydro Resource Model. 2007 International Conference on Clean Electrical Power, Capri (Italy), 21-23 May 2007.*

4. *EIU (2006-2009) Equatorial Guinea: Country Reports, The Economist Intelligence Unit Ltd., The Economist Newspaper Group, London (UK).*

5. *Alfaro-Pelico, R.I. (2010) Africa and Climate Change: Impacts, Policies and Stance Ahead of Cancún, ARI 173/2010, Real Instituto Elcano, Madrid (Spain).*

6. *Alfaro-Pelico, R.I. (2012) Small Island Developing States and Climate Change: Effects, Responses and Positions beyond Durban, WP 1/2012, Real Instituto Elcano.*

7. *Alfaro-Pelico, R.I. (2013) "Sustainable Energy for All" Approach to SIDS: A Case Study from Dominica. Paper, in: (2013) Leal Filho, W., et. al. (eds) Climate-Smart* Technologies. Springer, Berlin. https://doi.org/10.1007/978-3-642-37753-2_13.

8. *UNDP (2013) Derisking Renewable Energy Investment, led by Waissbein O., et. al. with input by Alfaro-Pelico, R. et. al. United Nations Development Programme.*

9. *IFC (2017) Creating Markets for Climate Business, led by Kerr, T. with inputs from Alfaro-Pelico, R. et. al., International Finance Corporation, Washington (USA).*

10. *IMF (2018a) Saint Lucia: Climate Change Policy Assessment, IMF Staff Country Report No. 2018/181 led by Cheasty, A., et. al. with input from Alfaro-Pelico, R. et. al. (World Bank), International Monetary Fund, Washington, DC (USA).*

11. *IMF (2018b) [Belize: Climate Change Policy Assessment](), IMF Staff Country Report No. 2018/329 by led by Cheasty, A., et. al. with input from Alfaro-Pelico, R. et. al. (World Bank), International Monetary Fund, Washington, DC (USA).*

12. *Alfaro-Pelico, R. (2022a) Three Benefits of a People-Centric Energy Transition in the Global South, Rocky Mountain Institute, Basalt, CO (USA).*

13. *Alfaro-Pelico, R. (2022b) Energy transition partnerships in the Global South. OPEC Fund for International Development, Vienna (Austria).*

14. *Alfaro-Pelico, R.; Gumbs, D. (2022) Catalyzing the Caribbean's Clean Energy Transition through Strong Partnerships, Rocky Mountain Institute (USA).*

15. *Lázaro Touza, L. and Alfaro-Pelico, R.I. (2022) COP 27 in Sharm El-Sheikh: from climate frustration to radical implementation?, Real Instituto Elcano (Spain).*

16. *Alfaro-Pelico, R.; Babamanu, S.; Chikumbo, M. (2023) Closing Nigeria's Power & Green Skills Gaps: Pathway to Increased Energy Access, Rocky Mountain Institute.*

17. *Bloch, C.; Pesta, N.; Tyson, and Alfaro-Pelico, R. (2023) Realizing the Green Jobs Promise: The Benefits of a Regenerative Approach, Rocky Mountain Institute (USA).*

18. *IEA, IRENA, UNSD, World Bank, WHO (2024) Tracking SDG 7: The Energy Progress Report, World Bank, Washington DC (USA). © (CC BY-NC 3.0 IGO).*

19. *IRENA and ILO (2024), Renewable energy and jobs: Annual review 2024, International Renewable Energy Agency, and International Labour Organization.*

20. *IRENA (2024) A Just And Inclusive Energy Transition In Emerging Markets And Developing Economies, report for the G20 Brazil prepared under the guidance of Alfaro Pelico, R. et. al., International Renewable Energy Agency, Abu Dhabi (UAE).*

Many PhD thesis findings have also been appraised and disseminated at Lancaster University postgraduate research conferences, amongst other fora:

21. *Alfaro-Pelico, R.I. (2015) Barriers to the Deployment of Renewable Energy: "Research Proposal", appraisal progress report presentation at the 2015 Postgraduate Research Conference, Lancaster University (UK), 30 June 2015.*

22. *Alfaro-Pelico, R.I. (2020) Barriers to the Deployment of Renewable Energy – Application of the NWRHM and DREI Model in Developing Countries, field research presentation, Postgraduate Research Conference, Lancaster University, 2 July 2020.*

23. *Alfaro-Pelico, R.I. (2021) Barriers to the Deployment of Renewable Energy: "Equatorial Guinea, Namibia, Tajikistan", site visit comparative presentation at the 2021 Postgraduate Research Conference, Lancaster University (UK), 30 June 2021.*

24. *IRENA (2024) Derisking Investments towards Realising SDG7, Session at the 27th IRENA Council, International Renewable Energy Agency, 13-14 June 2024.*

Abstract

The thesis assesses the barriers to the deployment of renewable energy. Main reference sequential decision-making and derisking models used to assess these include Lancaster University's North-West England Hydro Resource Model (NWHRM) and the United Nations Development Programme (UNDP) Derisking Renewable Energy Investment (DREI) model. Their applicability to alternative renewable energy (RE) sources (mainly solar and wind), scales (from small-to-large RE generation capacities) and sites (from advanced economies to emerging markets and developing economies) is studied to establish their relevance. Based on case studies and field research across countries in Sub-Saharan Africa (Equatorial Guinea, South Africa, Namibia); Latin America (Panama, Paraguay); Central Asia (Mongolia, Tajikistan); and the Caribbean (Barbados, Jamaica), the thesis identifies that technical, financial, regulatory, and socio-political barriers are often interlinked and context dependent. While the NWHRM effectively captured physical, geographic, and infrastructure constraints, its principles needed adaptation of key social acceptability, institutional capacity, and climate resilience dimensions; meanwhile, the DREI model focus on financial derisking needed expansion of its consideration of non-financial risks, with policy derisking measures addressing information, regulatory framework and human capital limitations. Though financier's risk perceptions differ across technologies and geographies, the underlying categories of market, policy, technical, and social risks remain consistent across emerging markets and developing economies vis-à-vis advanced economies. Overall, the thesis reveals that a wider range of policy and financial derisking instruments reduce the levelised cost of energy, improving investment efficiency and market entry conditions for renewables. Measures integrating governance, social acceptance and human capital development dimensions enhance NWHRM and DREI model capacity to assess systemic barriers to a renewables-based just and inclusive energy transition. Sequential decision-making models and derisking such as these are complementary and can evolve into globally-relevant approaches to address barriers to renewable energy investment.

Acknowledgements

This thesis would have not been possible without the love and patience from my wife Asha Imani Bobb-Semple and children Enoâ, Tsandze and Nalah; nor would have been feasible without the resolve and persistence from my PhD supervisors Prof. George A. Aggidis and Dr. David C. Howard.

After several years searching for doctoral programs at universities worldwide with research interest in the intersection of energy transition and innovation; ecology restoration and conservation; and, economy-wide effects of climate change mitigation and adaptation, Prof. Aggidis and Dr. Howard provided me with the unique opportunity to embark on a truly inter-disciplinary journey to assess the barriers to deployment of renewable energy.

Lastly, sincere appreciation to Dr. Mohammad Rahmati and Dr. Denes Csala for their feedback in the thesis examination, with credits to them for the improvements to the thesis in its final version. Any errors or omissions are strictly the responsibility of the author, as the thesis is publicly available for academic and research purposes only. The author, examiners, supervisors and the university accept no responsibility for any consequences arising from the use, misuse or interpretation of the material contained herein.

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List of Acronyms

BDRE	Barriers to Deployment of Renewable Energy
CSP	Concentrated Solar Power
DFIs	Development Finance Institutions
DREI	Derisking Renewable Energy Investment
EIA	Environmental Impact Assessment
EM	Emerging Markets
EMDEs	Emerging Markets and Developing Economies
FIT	Feed-In Tariff
G20	Group of Twenty Countries
GEF	Global Environment Facility
KPI	Key Performance Indicators
IEA	International Energy Agency
IFC	International Finance Corporation
IMF	International Monetary Fund
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
LCOE	Levelised Cost of Energy
LDCs	Least Developed Countries
LU	Lancaster University
MDBs	Multilateral Development Banks
NWHRM	North-West Hydro Resource Model
OECD	Organization of Economic Co-operation and Development
PhD	Doctor of Philosophy
PPA	Power Purchase Agreement
RE	Renewable Energy
RIE	Real Instituto Elcano
RMI	Rocky Mountain Institute
SDM	Sequential Decision-Making
SEforALL	Sustainable Energy for All
SIDS	Small Island Development States
SSA	Sub-Saharan Africa
UK	United Kingdom
UNDP	United Nations Development Programme
UNSD	United Nations Statistics Division
WB	World Bank
WHO	World Health Organization

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1 Introduction

1.1 Context

The thesis proposes the development of a globally applicable framework that identifies barriers to renewable energy deployment across diverse investment locations, resources and scales. To this effect the thesis applies sequential decision-making and derisking models, such as the Lancaster University's North-West Hydro Resource Model (NWHRM) and the United Nations Development Programme's Derisking Renewable Energy Investment (DREI). The NWHRM was originally developed to assist in the decision-making process of small-scale hydropower projects in England, while the DREI model was originally framed to support decision-making process of large-scale wind power projects in emerging markets and developing economies (EMDEs). The NWHRM uses a single site as demonstration of the process , while the DREI approach has been applied to different sites across less developed countries From the project developer's perspective, the NWHRM assumes that the decision to build is made on an economic basis, while also considering other aspects that inform such investments (engineering options, resource capacity, environmental implications, public acceptability). From the financier's perspective, DREI approaches risk from both a policy and financial standpoint. This thesis draws on mixed research methods to assess in practice barriers in both wind, solar and hydropower deployments across regions to test the applicability of these models.

1.1.1 Background

While searching for a university where to undertake doctoral research over a decade ago the authored struggled to find academic interest in supervising a thesis on the challenges and opportunities of investing in climate change mitigation and adaptation in emerging markets and developing economies (EMDEs). At the time, the author's interest was driven by his professional experience in the subject matter, as a Regional Technical Advisor at the United Nations Development Programme (UNDP).

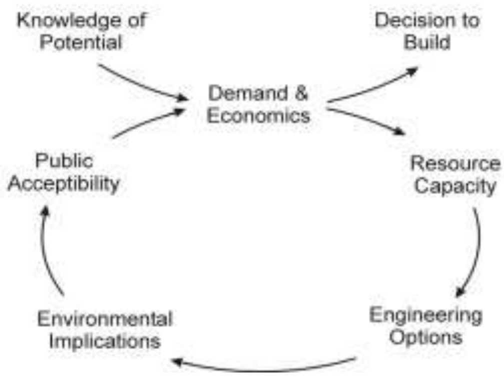
Since 2009 the author advised EMDEs in Africa and the Americas on how to access funding to invest on climate change projects (e.g., renewable energy, energy efficiency, infrastructure resilience). A key part of this support was the identification of barriers that needed to be removed, as well as the risks that needed to be mitigated for finance to flow towards renewable energy deployment, energy efficiency or technology transfer implementation. The type of barriers to deployment identified were ranging from legal and political (e.g., lack of energy plans, climate strategies, policies, licenses and regulations); technical and institutional (e.g., inadequate procurement and permitting processes, limited skillsets, knowledge and capabilities); to financial and commercial (e.g., unawareness of the costs and benefits of renewable energy resources, limited incentives vis-à-vis fossil fuel options, lack of economies of scale and access to financing); amongst other social, environmental and multidimensional issues constraining renewable energy finance flows to EMDEs.

After exploring research programs outside the United Kingdom (e.g., University of Cape Town, South Africa; Instituto Empresa, Spain), and British universities (i.e., the author's alma mater, School of Oriental and African Studies, other colleges of the University of London, e.g., London School of Economics and Political Science, and other British universities, e.g., University of Surrey, Sussex and Leeds), the author landed at Lancaster University. Most universities did not allow distance learning options, essential for the author to afford undertaking doctoral studies while also working. Universities allowing remote options at the time, combined them with residence, which the author could not entertain either.Interest in linking climate change and sustainable development was also very limited. Lancaster University, however, had developed the North-West Hydro Resource Model assessing the barriers to small-scale hydropower developments in the UK (Aggidis, Howard et al., 2006). The authors underscored a somewhat contrasting but similar challenge for renewable energy deployment, this time in an advanced economy. The mature nature of hydropower as a proven technology, was also seen as a renewable resource with limited opportunity amidst increasing diversification of clean energy supplies (e.g., wind and solar), and comparatively limited finance flows to small scale hydroelectric deployment.

This research was coincidentally published the same year of the first publication in the author's literature review (Etezadi-Amoli et al., 2006), and further refined the following year (Leigh, Aggidis, Howard et al., 2007), as the only theme that at the time was underscoring the intra-disciplinary nature of the barriers to development of renewable energy. It was also a coincidence that it was the only university the author came across that accepted distance learning and considered work experience as part of research (e.g., the Professional PhD).

A major breakthrough for the author was the possibility of undertaking engineering-oriented research, with joint research supervision that would integrate the academic areas of energy and ecology. It built on the author's graduate education in applied economy-wide effects of natural resources management in EMDEs, and undergraduate studies in business administration. The clearest depiction of the sought alignment with taking an integrated approach to renewable energy investment was the NWHRM (*Figure 1*, below):

Figure 1: NWHRM Sequential Decision Making Process

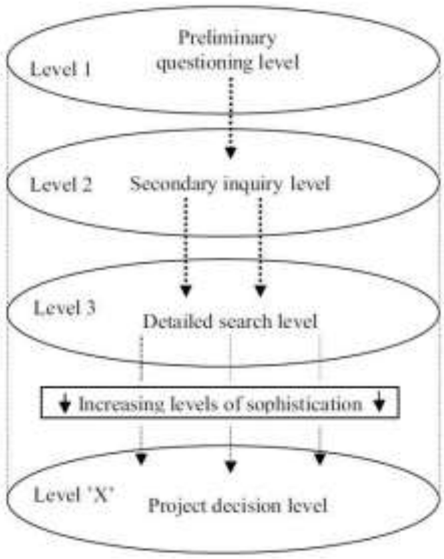


Source: Aggidis, Howard et al., 2006

The possibility of incorporating in the author's research the social, natural, technical, commercial and environmental implications of removing barriers and mitigating risks for renewable energy investment was somewhat a blessing in disguise at the time. It matched his day-to-day job, which required constant application of the NWHRM iterative decision-making process; however, his exposure lacked the benefit of going into its depth and sequence of inquiry, as depicted in *Figure 2* (below), due to the data and time limitation of his profession.

Based on the author's years-long search for a university, it was also important for the research department to find interest and complementarity between the proposed doctoral thesis and the LU Engineering Department body of work. Here is where the niche and potential contribution to knowledge came about. The NWHRM was developed to assess the barriers to small-scale hydropower developments in the United Kingdom. Its original study focused on North-West England, designed to assist developers as a decision support tool.

Figure 2: NWHRM Multi-Level Sequential Decision Making Process



Source: Leigh, Aggidis, Howard et al., 2007

The use of the DREI model was complementary to the application of the NWHRM. It helped deepen the economy-wide dimensions of the assessment of barriers and further built on the author's graduate and post-graduate education. The NWHRM involves cost-benefit analyses as part of its sequential decision-making process, with clear focus on its demand and economics stage. It strengthened the integration of the ecology and economy aspects of renewable energy deployment, and the application of DREI and NWHRM to find investment and development implications in these decisions, specially in EMDEs.

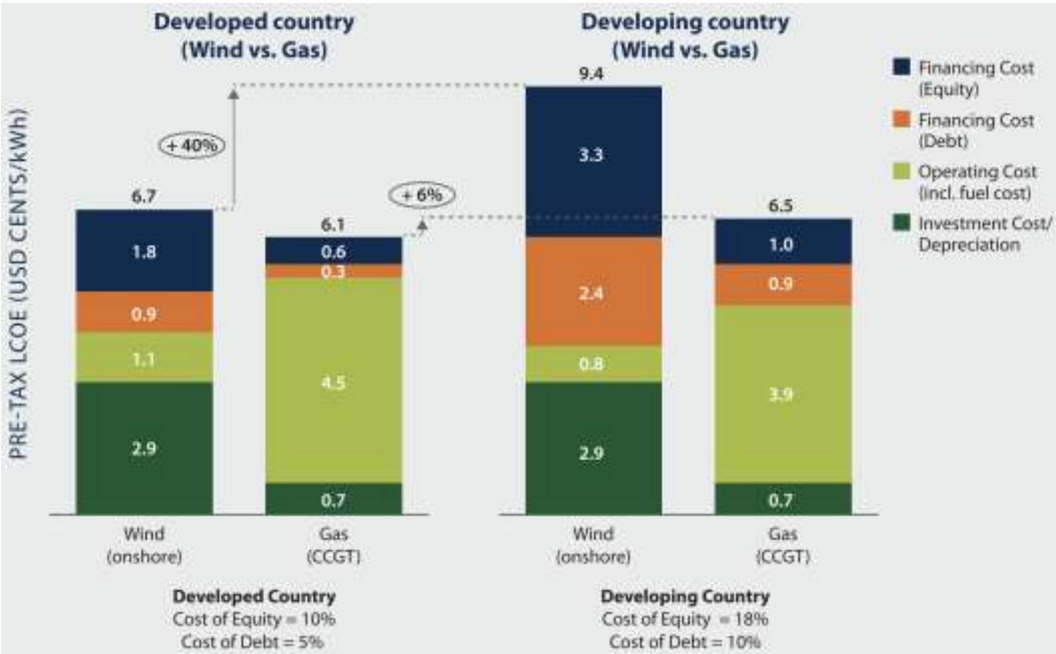
Development finance institutions (DFIs) like the United Nations, World Bank, donor agencies and multilateral development banks (MDBs) rely on grants (non-reimbursable funds) from various sources (own budget, trust funds, donor resources) for various barrier removal activities (institutional strengthening, technical assistance, capacity building, analytical support, pilot demonstrations). Neither small nor large-scale renewable energy developments can solely be funded by grants, due to criteria against it or investment sizes requiring non-grants (debt, equity, innovative finance mechanisms). The DREI framework acknowledges this by distinguishing policy derisking instruments (incl. grant mechanisms) from financial derisking instruments (incl. non-grant mechanisms). It also underscores that while finance is widely available to invest in clean energy projects in OECD countries, capital providers argue there is a lack of bankable projects in EMDEs. This issue was apparent when applying the NWHRM in Africa.

The NWHRM has been used in the research thus far as a framework to understand the interrelated energy, ecology and economy dimensions of investment in renewables in Sub-Saharan Africa (SSA). The author's field visits to hydropower deployments in Equatorial Guinea not only underscored some barriers that might already be addressed in developed countries, but also risks that need to be mitigated for needed investments to materialize.

The cost-benefit analysis inherent to the NWHRM thus needs to be expanded to assess how renewable energy developments consider the risk-return dimensions introduced by the United Nations Development Programme's "De-risking Renewable Energy Investment" model (UNDP, 2013). Key to this assessment is understanding the barriers that drive the cost of capital inherent to renewable energy deployment in developed countries vis-a-vis emerging markets and developing economies (EMDEs). The DREI framework offers an approach to assess what is needed to address them. As the site visits showed, the project proponents in EMDEs often face challenges in securing the large amounts of financing required for renewable energy deployments. The DREI report shows that when financing is available, the costs are significantly higher than in developed countries, leading to increased power generation costs for renewable energy technologies.

The disparity in financing costs (both debt and equity) can greatly impact the competitiveness of renewable energy compared to fossil fuels in EMDEs. As *Figure 3* illustrates (below), the framework draws a comparison between the 2012 levelized cost of electricity (LCOE) for an onshore wind plant and a combined-cycle gas plant in both a developed and a developing country. In developed countries, where financing costs are low, wind power can be nearly competitive with natural gas, even with gas being relatively affordable. However, in developing countries, where financing costs are higher, the capital-intensive nature of wind technologies results in wind power generation being 40% more expensive than gas:

Figure 3: Comparative Financing Wind and Gas Costs



Source: UNDP (2013)

The author's field research in Equatorial Guinea showed how while its mainland region had a primarily renewable energy matrix, dominated by hydropower along the Congo river basin, the island regions relied significantly on fossil fuels to meet their energy demand. The oil and gas sector access to capital and technology was unmatched by that of the renewable energy sector. The DREI framework underscores that higher financing costs in EMDEs are due to various perceived or real risks. These include informational, technical, regulatory, financial, and administrative challenges, leading to increased investment risks.

The DREI model proposes that to attract private investment in renewable energy deployment, EMDEs may need to offer very high returns to investors. This is especially considered the case if independent power producers (IPPs) encounter obstacles such as limited grid access, lengthy and uncertain permitting processes, a shortage of local expertise, or a lack of long-term price guarantees.

It resonates with some of the barriers addressed in the Equatorial Guinea site and other visits throughout the research period. The following sections provide an overview of the DREI framework and applies it to other field research.

The aim is to highlight additional challenges in funding the shift to a low-carbon energy system, and show that lack of capital is one, but not the only need, to address existing investor risks that drive up financing costs. The evidence should show whether these risks, whether real or perceived, hinder the competitiveness of renewable energy deployment in EMDEs, calling for the need of a broader understanding of derisking instruments to mitigate them.

The DREI framework was introduced in 2013 with the release of the initial DREI report (UNDP, 2013). The author contributed to the conceptualization and implementation of this framework drawing on his previous experience supporting the removal of barriers of renewable energy projects across EMDEs.

The DREI report initially concentrated on large-scale renewable energy projects. It outlined the methodology's change theory, highlighting the importance of lowering the higher financing costs incurred by renewable energy projects in developing countries than in developed economies, as a critical priority for policymakers.

The framework aims to help these policymakers choose and assess the effects of public measures to boost investment in renewable energy. In turn, these can also contribute to broader national goals, such as improving energy access, enhancing energy security, and reducing climate risks. Its underlying theory of change suggests that lowering financing costs in EMDEs offers country opportunities to attract private investment.

It considers that renewable energy projects involve high upfront costs, low operating costs and therefore are particularly sensitive to financing costs. In developing countries, these costs are generally elevated due to additional perceived barriers. Based on this approach, the DREI model explores how derisking instruments can help address these barriers, lower financing costs and also reduce life-cycle costs. The framework considers the following phases: (i) risk environment, (ii) public instruments, (iii) levelized cost, and (iv) evaluation.

1.1.1.1 Risk Environment

The DREI model at this stage seeks to identify how investment barriers lead to increased risks. These in turn raise the financing costs for renewable energy projects. The first step involves identifying relevant barriers and risk categories associated with renewable energy deployment. The second step involves quantifying how these risks impact the cost of equity and debt. The result of these steps is depicted in *Figure 4* (below), which includes a table analysing multi-stakeholder barriers and risks (assessing the probability of occurrence of negative events vis-à-vis their consequent financial impacts) and a chart showing what the DREI model describes as the "Financing Costs Waterfall"(illustrating the incremental contribution of each risk category to higher financing costs):

Figure 4: DREI Model Risk Environment (UNDP, 2013)

Engaging different stakeholder groups associated to the deployment of renewable energy helps to identify various risk categories. These categories are supposed to be independent of each other to avoid risk overlaps. Meanwhile, the gap between the cost of equity and debt between what the DREI model considers "best-in-class" economies (like OECD countries) and developing countries (such as EMDEs) is broken down into specific risk increments, quantifying the relative significance of various risks faced by investors.

For example, if a particular risk category is especially prominent in a developing country, its corresponding increment in that country's breakdown would be relatively large. This quantification helps guide the selection of measures (DREI model public instruments) to mitigate these risks and barriers, while also offering a way to assess how these interventions reduce financing costs.

1.1.1.2 Public Instruments

The DREI model at this stage focuses on understanding how specific public instruments can lower financing costs for renewable energy. Such instruments or "derisking measures" can be categorized into two main types:

- *Policy derisking instruments* – They focus on addressing and eliminating the underlying barriers that create risks, using policy and programmatic interventions to mitigate risks. For instance, renewable energy projects often require multiple permits and approvals, such as generation licenses, environmental impact assessments (EIAs), and land rights. Unclear or overlapping institutional responsibilities, or a lack of expertise in renewable energy, can increase transaction costs, delay project revenues, and discourage investment. These challenges resonate with those found at the Equatorial Guinea site visits. A policy derisking approach would simplify the permitting process, clarify institutional roles, reduce procedural steps, and provide capacity building for key stakeholders.
- *Financial derisking instruments* – They shift the risks faced by investors to public entities, such as MDBs, rather than tacking root barriers. These instruments may include loans, guarantees, political risk insurance, or public equity co-investments. While they do not directly address the barriers, they can indirectly influence them through experience and track record effects. Countries with underdeveloped financial sectors, local banks may be hesitant to lend to the renewable energy sector due to its unproven nature. Partial loan guarantees from an MDB can provide the confidence needed for local banks to extend loans, as part of the risk is transferred to a public entity. Financial derisking instruments can help activate the engagement of local financial sector's in renewable energy.

In the first step, public instruments that directly address the identified barriers and risks are selected. The second step measures the effects of these instruments on reducing costs of equity and debt. Both steps are depicted in *Figure 5* (below):

Figure 5: DREI Model Public Instruments (UNDP, 2013)

BARRIER	RISK CATEGORY	POLICY DERISKING INSTRUMENT	FINANCIAL DERISKING INSTRUMENT
Barrier #1	Risk #1	Instrument #1	
Barrier #2		Instrument #2	
Barrier #3	Risk #2	Instrument #3	Instrument #4

The selection of public instruments is driven by the types of risks that need to be addressed, as identified in the previous stage. The DREI model aims to match these measures and interventions with the risks and barriers at hand in a particular risk environment.

For instance, several challenges were identified with the power sector in Equatorial Guinea. One of them was the existence of a draft Energy Law that was awaiting adoption. It created uncertainty for market players, developers and financiers, as they were unclear about the country plans, targets and strategies for the electricity sector. Some measures that Equatorial Guinea could have considered included the establishment of processes (e.g., tenders, auctions, power purchase agreements) that give transparency to price, market signals, or the role different institutions (i.e., SEGESA as the national electricity utility, MMIE as the ministerial department mandated with energy regulation).

Once the range of policy and financial derisking instruments are chosen, the next step is to assess their costs and impact to reduce financing costs. These estimation processes are based on quantitative and qualitative data gathered from stakeholders in the particular risk environment. They will be driven by facts and interviews that consider real evidence, and perceptions from relevant actors.

1.1.1.3 Levelised Costs

This stage analyses how reduced financing costs affect the overall life-cycle cost of renewable energy projects. The first step calculates the levelized cost of energy (LCOE) for the energy mix.

The second step calculates the LCOE for renewable energy investments, comparing pre- and post-risk mitigation financing costs to assess the incremental cost gap after the investment – see *Figure 6* (below):

Figure 6: DREI Model LCOE Incremental Gap (UNDP, 2013)

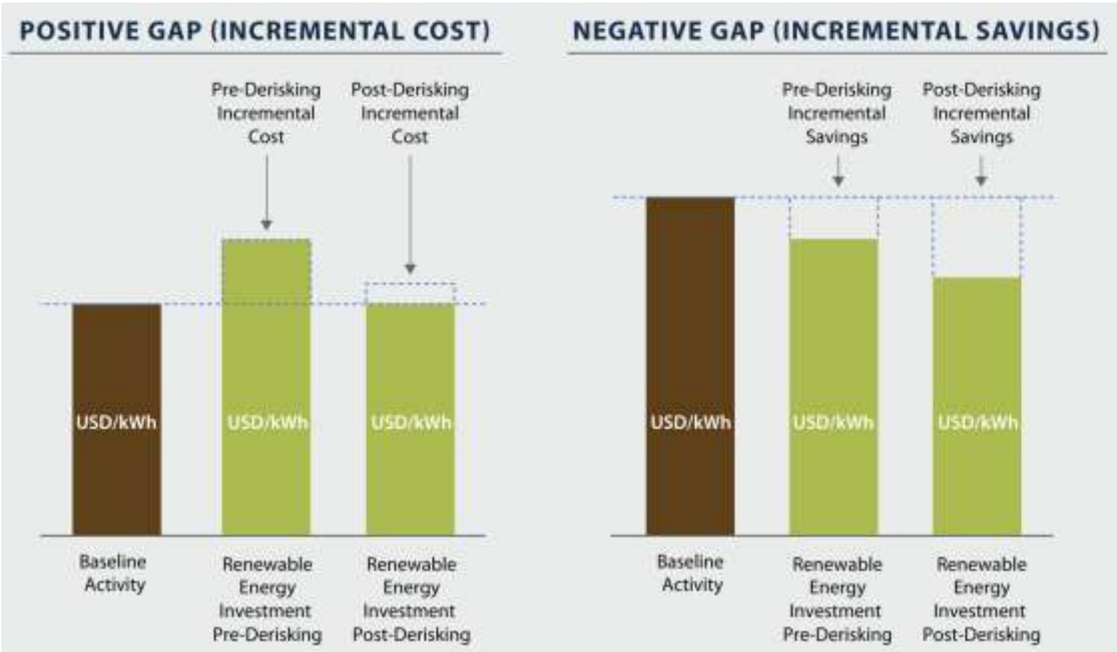
In the first step of the DREI Model LCOE stage, the estimation of the generation cost of the baseline energy mix requires identifying the technologies included in it, calculating the levelized cost of energy for each, and a weighted average cost. The step reflects that renewable energy deployments are not made in isolation, and take place within the context of an evolving domestic energy generation mix.

The baseline energy mix refers to either the electricity generation that will be displaced by the new renewable capacity or the generation that would be added if the deployment did not take place. It may include a variety of energy sources (e.g., renewables, nuclear, fossil fuels), and thus informs the competitiveness of intended deployments, and incentives that are needed to make it them attractive.

The second step of the Levelized Cost Stage involves calculating the life-cycle costs of the renewable energy investment under two scenarios: (a) *Pre-derisking scenario*, which reflects the financing costs before applying public derisking instruments identified in the DREI Model Risk Environment stage; (b) *Post-derisking scenario*, which reflects the financing costs after the use of public derisking instruments, and the cost of financial derisking measures to be borne.

As a result, this step requires data on operational and investment costs for the specific renewable energy technology under consideration, to compare the LCOE of the renewable energy scenarios with that of the baseline energy mix. This comparison is a key outcome of the DREI framework and offers insight into whether renewable energy is competitive with the baseline and what the incremental costs or savings are compared to the baseline. These comparisons are depicted in *Figure 7* (below), with two possibilities: one with a positive gap (incremental cost) and one with a negative gap (incremental saving):

Figure 7: DREI Model LCOE Incremental Comparisons (UNDP, 2013)



In the positive gap scenario, renewable energy has become more competitive after derisking but remains more expensive than the baseline. This means, an incremental cost still exists, and so policymakers would need to provide financial incentives (e.g., price premiums, subsidies) additional to any policy or financial derisking instruments. In the negative gap scenario, renewable energy is more competitive than the baseline both before and after applying public instruments.

1.1.1.4 Evaluation

The DREI model at this stage evaluates the selection of public instruments applied to derisk renewable energy investment against cost, efficiency and effectiveness performance metrics, and undertakes sensitivity analyses.

In the first step (see *Figure 8*, below), key performance indicators (KPIs) or metrics include the:

(a) *investment leverage ratio*, comparing the effectiveness of public instruments in catalysing private investment;

(b) *savings leverage ratio*, assessing the cost of derisking instruments applied vis-à-vis the economic savings emerging from the use of such instruments;

(c) *end-user affordability*, comparing the LCOE of renewable energy in the post derisking vis-à-vis the pre-derisking scenario, and;

(d) *carbon abatement*, considering the potential vis-à-vis the costs of renewable energy investment from a climate change mitigation perspective.

In the second step, the DREI framework evaluates data and assumptions on barriers to investment, renewable energy resources, technology and financing costs of the chosen technology, the country's baseline energy mix and the costs associated with the selected public instruments.

Figure 8: DREI Model Evaluation Stage (UNDP, 2013)

The data collection, verification and dissemination undertakings here are critical to apply the framework, address assumptions transparently, and assess results that can be compared to support decision-making on the choice of public instruments to derisk renewable energy investment – see selected parameters assessed in *Figure 9* (below):

Figure 9: DREI Sensitivity Analysis Drivers (UNDP, 2013)

Stage 1:	Risk Environment	• Best-in-class country selection	
Stage 2:	Public Instruments	• Public instrument effectiveness (impact on cost of debt & equity, capital structure, loan tenors) • Public instrument timing effects • Cost of financial derisking instruments (including [paid-in-capital leveraging]) • Cost of policy derisking instruments	
Stage 3:	Levelised Cost	**Baseline LCOE** • Existing vs. marginal baseline • Energy mix ∘ Investment costs, O&M costs ∘ Fuel costs (unsubsidised vs. subsidised, market projections) ∘ Capacity factor ∘ Financing (cost of debt & equity, capital structure, loan tenors)	**Wind LCOE** • Investment costs • Capacity factor • Financing (cost of debt & equity, capital structure, loan tenors)
	General	• Public sector discount rate • Tax rates • Depreciation	

The next chapters illustrate case studies of the application of the full DREI framework that the author contributed to its theoretical conceptualization and practical demonstrations. It will draw on the mix blend of research methods laid out in this chapter, and practices in emergent markets and developing economies.

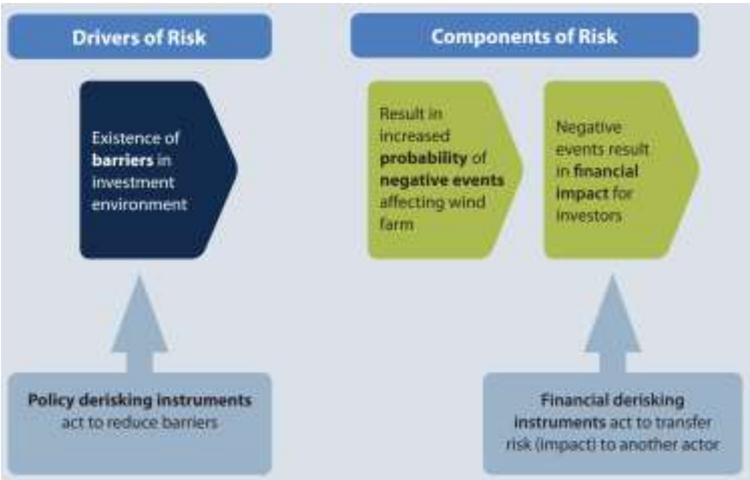
To assess how the DREI framework has supported barrier identification efforts to address challenges in the deployment of renewable energy, this section includes additional findings the author came across from site visits, case studies and main insights from projects and stakeholders during the research period.

The derisking renewable energy instruments explored include investments in energy sources other than hydropower, including solar and wind power. The deployments also take place outside of the UK, to continue the identification of barriers in non-OECD countries.

The expectations of both NWHRM and DREI model applicability in EMDEs are assessed in regions with different risk environments, public instruments, costs of electricity and KPIs at hand.

The applications include countries with diverse end-user affordability, carbon abatement, savings and investment leverage potential across Sub-Saharan Africa (such as South Africa and Namibia); Latin America (covering Panama and Paraguay); and, the Caribbean (including Jamaica, Grenada and Saint Lucia). The diversity of cases seeks to illustrate different elements of how the DREI framework identifies risks, barriers and measures that might have not been considered in NWHRM sequential decision-making (SDM), see *Figure 10* (below):

Figure 10: Policy and Financial Derisking Effects



Source: UNDP (2013)

The case study range includes derisking applications for the same or different renewable energy sources (i.e., hydropower vis-à-vis solar and wind), scales (e.g., North-West of England combined 4.3 MW sites vis-à-vis Parana river basin 14 GW-sized Itaipú plant) and sites across Small Island Development States (SIDS), Least Developed Countries (LDCs) and Emerging Markets (EMs). These examples help inform some policy interventions to derisk renewable energy investments.

Thus, the scope of the thesis and research proposal was focused on identifying the barriers to the deployment of renewable energy and exploring the NWHRM and DREI model as reference sequential decision-making approaches for different sources (wind, solar, hydro); scales (small, medium, large); and sites (EMDEs across regions).

The NWHRM was selected because it was initially developed to assess barriers to small-scale hydropower in the UK and offered a structured approach to sequential decision-making that could be adapted to alternative renewable energy contexts. The DREI model was chosen due to its ability to identify risks and address their underlying barriers to deployment in EMDEs as a comparison. Their relevant applicability was considered in line with the following criteria:

1. Geographic Transferability – Evaluating whether the model principles could be adapted to diverse geographies with different socio-economic conditions.

2. Energy Source Versatility – Assessing whether the model could potentially handle different renewable resources and technologies (e.g., solar, wind, hydro).

3. Size Scalability – Checking whether the model could be effective in both small-to-medium scale and large-scale renewable energy investments.

4. Financial and Regulatory Compatibility – Checking if model parameters could fit other market conditions, regulatory frameworks and enabling environments.

5. Social and Technical Capabilities – Looking at factors such as public acceptability and infrastructure feasibility when applying them in new contexts.

1.1.2 Research Proposal

The PhD thesis proposal assesses whether the NWHRM is applicable to different geographic locations, renewable energy resources and installed generation sizes.

The author's job focused on similar developments in developing countries, not only for hydropower but also wind, solar and other small, medium and large-scale investments. The thesis draws lessons on risks and barriers from their initial development to their final deployment in the Americas, Asia and Africa.

In the process of determining the research scope, and exploring the opportunities for knowledge contribution, many publications written by the author before and during the doctoral research had assessed the benefits of considering different sites, scales and sources of renewable energy deployment.

Some of the author's previous research, into African sites, had focused on the impacts and measures needed to respond to the threats posed by climate change. Both mitigation and adaptation actions were examined, covering technology interventions and finance options (Alfaro-Pelico, 2010).

In addition, the specific circumstances of Small Island Development States (SIDS) were assessed, and priority actions considered for a very heterogeneous geographic grouping (Alfaro-Pelico, 2012), with homogeneous challenges (small scale, large vulnerability) to apply the NWHRM. The thesis seeks to develop an understanding of risks, barriers, and solutions for the deployment of renewable energy drawing on theoretical models and actual projects at different stages of deployment. In the process, it seeks to identify any constraints related to the investment scale, renewable source and project site.

This is both to assess the applicability of the Derisking Renewable Energy Investment (DREI) model (UNDP, 2013) and NWHRM frameworks, and recommend modifications so the models can be applicable worldwide. Specific features and parameters warrant consideration for adaptation in NWHRM and DREI models. They include:

1. Financial and Regulatory Conditions – the DREI model's assumptions about financial derisking mechanisms (e.g., non-grant instruments) need attention to local regulatory, market, and economic conditions. Developed economies, with more mature regulatory structures should require fewer financial interventions compared to EMDEs more reliant on international funds.

2. Geographic and Ecological Environments – the NWHRM requires modifications to be applicable to larger projects (e.g., high-head hydropower sites, high generation capacity wind and solar farms), diverse locations (e.g., remote or isolated locations, climate vulnerable sites) presenting other unique challenges.

3. Climate Risk and Vulnerability Integrations – the NWHRM and DREI models need to address short-to-medium-term climate scenarios in locations where hydropower, solar and wind technical and financial performance are affected by variability.

4. Scalability and Investment Size Considerations – the NWHRM and DREI models need adaptations to constraints linked to limited economies of scales, not only for low-head hydropower, but also mini- or micro- solar-powered grids and wind sites without large resource endowments particularly in poorer EMDEs regions.

5. Individual and Institutional Capability Modifications – the NWHRM and DREI models need to consider humans as resources, not only as social agents influencing public acceptability, but also as actors in the sequential decision-making process alongside natural, physical and financial capital considerations.

The thesis seeks to improve NWHRM, DREI and any other sequential decision-making and derisking models' ability to identify and evaluate barriers through:

a) Enhanced Contextual Relevance – Incorporating geographic and socio-economic variations making these models more adaptable globally.

b) Improved Risk Mitigation – Including climate and social risks and helping to identify context-specific barriers earlier in the decision-making process.

c) Enhanced Benefits – Adjusting financial assumptions for advanced versus emerging markets and developing economies, improving the assessment of costs, benefits, impacts and rewards inherent to barrier analysis and risk assessments.

d) Scalable Solutions – Addressing scale-specific challenges and ensuring that both small and large renewable energy projects are evaluated appropriately.

e) Social Inclusion – Recognizing human capital challenges and opportunities, enabling more holistic assessment of renewable energy deployment impacts.

The NWHRM and DREI models support decision-making for the promotion of renewable energy investment in, respectively, developed and developing economies. The thesis’s main contribution to knowledge lies in the provision of evidence of common and different challenges and opportunities in such deployments across a range of sources, scales and sites.

In doing so it broadens the understanding of the policy and financial instruments necessary to address barriers and manage risks both in developed and developing economic contexts.

1.1.3 Doctoral Thesis Structure

The thesis starts with a review of the literature exploring barriers to deployment of renewable energy (Chapter 1). It focuses on the Lancaster University's North-West Hydro Resource Model and the United Nations Development Programme's Derisking Renewable Energy Investment model, while also covering other relevant frameworks and bibliographic references.

The review subsequently provides an overview of the research methodology undertaken to assess these barriers. It considers both theory and practice relevant to gather evidence on the applicability of these models. The research continues with an initial focus on the application of the NWHRM to alternative renewable energy sites, scales and sources in Sub-Saharan Africa (Chapter 2).

It seeks to assess whether other barrier removal approaches to deployment, especially in emerging markets and development economies, are consistent with approaches in the North-West of England. This research contribution to a broader understanding of the general applicability of the NWHRM is expanded to the potential identification of other barriers when considering the DREI model in other countries across Sub-Saharan Africa (Chapter 3), Latin America (Chapter 4), Central Asia (Chapter 5) and the Caribbean (Chapter 6).

With the introduction of non-grant mechanisms, such as loans, credits and other financial instruments, to unlock the deployment of renewable energy, each chapter also explores the implications for different countries engaged in international climate negotiations. The related environmental risk management implications and engineering options of these deployments' outcomes are also covered in each chapter. With this theoretical and practical evidence at hand, the thesis moves on to consider other potential variations to both DREI and NWHRM decision frameworks (Chapter 7).

Research shows that the general applicability of these models requires other policy and financial derisking interventions that might not be available, particularly in emerging markets and developing economies.

These interventions also highlight constraints in some model features and parameters, which justify a deeper exploration of the social dimensions of a renewables-based energy transition.

This thesis concludes with a brief summary of the barriers assessed, the models explored, and the implications derived from various attempts to address the barriers to deployment of renewable energy (Chapter 8).

The chapter recommends areas for future research to further our understanding of the challenges and opportunities from a renewables-based, inclusive, equitable and just energy transition.

1.2 Overview

The North-West Hydro Resource Model was developed by Lancaster University assesses the barriers to low-head hydropower installations in the North-West of England. It draws from various disciplines, including engineering, ecological and economics sciences, to inform the decision to invest that might be relevant to other developed economies members of the Organization of Economic Co-operation and Development.

The Derisking Renewable Energy Investment framework was developed by the United Nations Development Programme to support the selection of policy and financial instruments to address the underlying barriers and transfer risks to enable the deployment of wind and solar power sources in emerging markets and developing economies. The following summarises the outcomes of the preliminary literature review focused on the thesis: "The Barriers to the Deployment of Renewable Energy" (BDRE). That is, it started with a review of bibliographic references found on Web of Science that included the key words of the thesis in its title (i.e., Barrier, Deployment, Renewable, Energy).

Subsequent literature reviews have also been considered, which show increased attention to the topic particularly over the last decade. Section 1.2.1 summarizes the initial findings of the preliminary literature review. Sections 1.2.2 introduces additional thematic searches undertaken broadening the review. Section 1.2.3 attempts to scope the focus of this PhD thesis.

1.2.1 Preliminary Literature Review

The initial filtering was undertaken on Web of Science in May 2024, returning thirteen (13) results of related publications explicitly including "Barrier", "Deployment", "Renewable", "Energy" (BDRE) with the following summary overview (see full list in *Appendix A*).

77% of the research (10 references in the sample) focused on a specific country or region, including members of the Organisation for Economic Co-operation and Development (i.e., OECD, e.g., Canada, Chile, Korea, Greece, Europe); emerging markets (e.g., Indonesia, India, Central Asia); as well as developing economies (e.g., Ghana, Zambia). The focus of the remaining 3 results was global.

The earliest publication of the initial literature search looked at the barriers and solutions associated with matching supply and demand for renewable energy (Etzeadi-Manoli et al., 2006). One additional publication looked at the effects of renewable energy deployment on fossil fuel prices (Foster et al., 2017), with a focus on key decision variables (e.g., costs, prices, demand, tariffs, location, subsidies, intermittency). The last publication (Seetheraman et al., 2019) broke down the barriers into categories (e.g., social, economic, technological, regulatory).

As each of the results show, the assessment of barriers to deployment of renewable energy varied. The approaches or frameworks to understanding them, or even addressing them included surveys and questionnaires. The energy sources ranged (e.g., wind, solar, ocean, fossil), and so did the renewable investment sizes (e.g. micro or small scale). One key factor, however, was the location.

This showed a need to consider geographic context matters not only from an ecological standpoint (what and where are the resources), but also from an economic (costs and benefits) and engineering (technical feasibility) viewpoint, as other studies show (Aggidis et al. 2006, 2007; Alfaro-Pelico, 2013; UNDP, 2013). In OECD countries, Krupa (2012) identified barriers in the Canadian Ontario province with a focus on the impacts on marginalised Aboriginal peoples. Key emphasis was made in understanding indigenous peoples' involvement in renewable energy generation. Nasirov, Silva and Agostini (2015) put the focus on investors, by identifying key barriers that project developers in Chile find with grid connection constraints and capacity, long lead times with permits, land and water leases and financing.

Kim (2021) underscored that despite the dramatic growth of renewable energy in Korea, several policy and regulatory developments are needed to ensure increased renewable energy offsets the phase out of traditional energy sources.

In emerging markets, the most comparable literature to the thesis included research from Laldjebaev, Isaev and Sukhimov (2021). They highlighted regulatory, infrastructure and financial barriers across Central Asian markets, different renewable energy sources (i.e., small-scale hydropower, solar PV, geothermal and wind) and scales (e.g., from 5-225 MW to 195-3,760 GW).

Comparing renewable energy investments in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, this cross-cutting study helped to tease out different levels of legal, physical, financial, technical and social barriers across sectors and how they are interrelated. Developing economies such as these face similar obstacles. Elsewhere in EMDEs, Sub-Saharan African countries find themselves at cross-roads between embracing the global clean energy transition and ensuring no one is left behind. The study by Bukari, Kemausuor and Adaramola (2021) underscored the need for distributed renewable electricity, such as mini-grids, in order to achieve universal energy access in Ghana. It used an analytical hierarchy process to rank barriers for mini-grid development using categories, including political, economic, technical, social and environmental.

The remaining (6 references) approached the topic without specifying a location and approaching the topic in generic terms from a framework perspective or considering different decision-making criteria.

Broadening the literature review to include other research categories that did not include the BDRE keywords (“Barrier”, “Deployment”, “Renewable”, “Energy” aimed to set the research in context). The focus on investment strategies, regulatory frameworks, technical challenges, or social justice was found irrelevant for the thesis due to the following scoping differences, keyword relevance and thematic divergences:

(a) Scoping Differences – The thesis specifically addresses barriers to the deployment of renewable energy using sequential decision-making and derisking models, while other titles focused on more academic general investment theory not specifically related to renewable energy issues. Others did not consider the multi-criteria decision analysis of interdisciplinary barriers inherent to the DREI and NWHRM.

(b) Keyword Relevance – The literature review strategy targeted publications directly addressing barriers, deployment, renewable energy, or energy-related challenges. Expanding the search scope led to unrelated topics or themes that would dilute the focus and compromise its coherence of the thesis, reflective of the comparatively lesser focus on these issues at the beginning (2009-2014) vis-à-vis the end (2019-2024) of the research period – see *Figure 3* in the next section 2.2.

(c) Thematic Divergence – Other titles and papers addressed macroeconomic policies or sustainable development in general without focusing on the practical actions on the ground that the barriers to renewable energy deployment identified by the DREI and NWHRM approaches required.

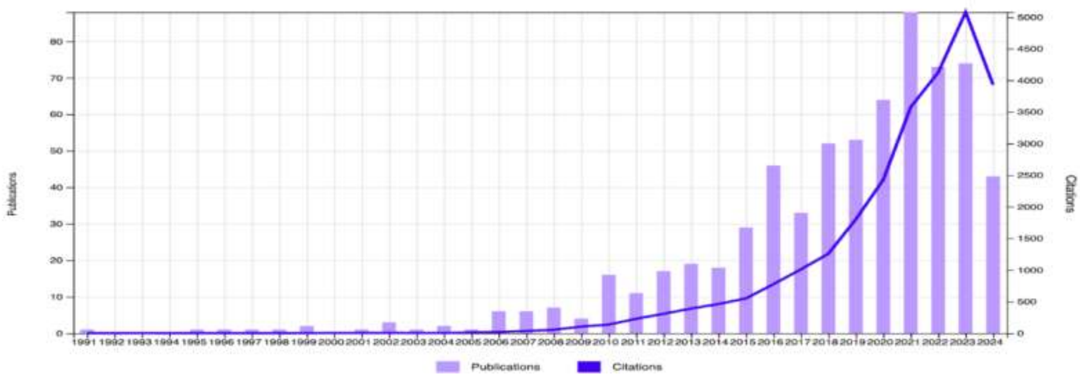
The aim of the literature review was to address the practical barriers to deployment of renewable energy; thus, several publications were not considered and the review concentrated on those relevant to the use of the NWHRM and DREI model.As a result, to refine the literature review the thesis did not include papers that tangentially related to the research questions, thus not significantly contributing to its novelty nor the advance of its objectives. The final thesis methodology intentionally focused on relevant theoretical analysis and practical research with a clear and consistent framing with the NWHRM and DREI models.

This thesis draws on stakeholder insights and related perspectives that other papers did not specifically include nor addressed the primary research questions. The next section expands the bibliographic references with an additional search undertaken in September 2024 that expands the topic coverage in various sources beyond the inclusion of key words in its title.

1.2.2 Additional Thematic Search

The complementary literature review for the same key BDRE words (i.e., Barrier, Deployment, Renewable, Energy) carried out in September 2024 returned 674 results depicted in *Figure 11* and *Table 1* (below, and expanded in *Appendix B*):

Figure 11: BDRE Theme Interest



Source: Web of Science (September 2024)

The main difference between the preliminary review in May 2024, and this complementary search in September 2024 include the large number of sources covering the barriers to deployment of renewable energy. It is the result of broadening the BDRE filter to all possible fields beyond the title field. The above depiction is needed as not all the literature is relevant despite growth in interest. The graph shows an exponential increase in publications that focus on barriers to deployment of renewable energy compared to when this doctoral thesis started.

One key consideration in both searches, the 1945-2024 timespan provided by Web of Science was not limited in time. Yet the May 2024 review shows that the earliest explicit inclusion of all key BDRE words in any title was 2006, with the latest being the 2022 sources listed in *Appendix A* covered in the previous section. It was an early indication of the relatively recent interest in the key BDRE words spanning less than two decades.

A similar reflection might be deduced from the September 2024 review, as the BDRE theme only starts growing in interest from 2006 onwards. It peaks in 2021 both in terms of publications and citations. It follows the entry into force of relevant multilateral agreements over the past two decades, such as the United Nations Vision adopted in 2015 that codified what today are widely known as the 2030 Sustainable Development Goals, or SDGs (UN, 2015).

Of note, the SDG that returned more results is Goal 7 "Ensure access to affordable, reliable, sustainable and modern energy for all". As *Table 1* shows, there is a linkage between the barriers to deployment of renewable energy and achieving sustainable energy for all:

Table 1: SDGs and BDRE Linkages

Sustainable Development Goals	Record Count	% of 674
07 Affordable and Clean Energy	493	73.16
13 Climate Action	112	16.62
11 Sustainable Cities and Communities	29	4.30
12 Responsible Consumption and Production	22	3.26
14 Life Below Water	10	1.48
15 Life On Land	8	1.19
06 Clean Water and Sanitation	6	0.89
09 Industry Innovation and Infrastructure	6	0.89
01 No Poverty	2	0.30
03 Good Health and Well Being	2	0.30
08 Decent Work and Economic Growth	2	0.30
02 Zero Hunger	1	0.15
10 Reduced Inequality	1	0.15

Source: Web of Science (September 2024)
52 record(s) (7.715%) do not contain data in the field being analysed

The author's past research while employed at the United Nations Development Programme was inspired by the early discussions of the sustainable energy topic. At the time, the author had visited the Commonwealth of Dominica in the Caribbean and used that experience to attempt framing an approach to addressing the barriers to deployment of renewable energy relevant for Small Island Developing States (Alfaro-Pelico, 2013). One of the main barriers the author experienced when promoting renewable energy in SIDS was the relatively lesser priority given to climate change mitigation issues, compared to the bigger priority given to climate change adaptation aspects. That research was one of the author's early attempts to reframe the way renewable energy deployment can both further reduce the relatively small carbon footprint of SIDS, while strengthening their resilience to adapt to climate change. This thesis scope further explains the need to go beyond such trade-offs.

1.2.3 Doctoral Thesis Scope

This section seeks to clarify where the content of my PhD thesis contributes to knowledge. The main thrust is that it draws on the know-how gathered and perspectives of the author's own experience studying and working on the removal of barriers to deployment of renewable energy. This starts with what led to the author to undertake doctoral studies in the first place, which was summarized as background in the preceding introduction. The thesis combines applied social, physical and environmental sciences drawing on the author's education in energy, ecology and the economy. His formal and vocational training in business administration and natural resource economics, with focus on developing countries, also integrated energy engineering with its combination of physics, chemistry and mathematics (see resume in *Appendix C*).

The resume provides a snapshot of the intellectual curiosity that led to learning experiences into various aspects of understanding the barriers to the global energy transition. They included several social, political, financial, commercial and environmental considerations informing the decision to invest in either fossil-fuel based energy and extractives industries (i.e., oil, gas and mining), or renewables-based energy sectors (e.g., power, other infrastructure).

These educational experiences equipped the author to then acquire a wide range of professional experiences with multinational corporations (e.g., Glencore, ExxonMobil and Noble Energy); multilateral institutions (United Nations Development Programme, World Bank, Inter-American Development Bank, International Finance Corporation, Sustainable Energy for All); and, multidisciplinary organizations across research, academia and civil society (e.g., Arcadia University and Drexel University with *Universidad Nacional de Guinea Ecuatorial*; The Economist Newspaper; and, Rocky Mountain Institute).

During these experiences, the author gained different perspectives on the factors that inform energy deployment decisions, and how to address them in order to accelerate the global energy transition. The thesis reflects that exposure, from the start of the research period in 2013, through its completion in 2023. Against this background, the thesis seeks to answer the following questions:

(1) Can sequential decision-making approaches like the NWHRM and derisking models such as DREI reviewed in the literature to assess barriers to deployment of renewable energy be developed into globally relevant generic models for any renewable energy source?
(2) How would model parameters need to be modified for their applicability in different areas of the world?
(3) Is the model constrained by the scale of deployment?

The primary frameworks considered to assess these barriers are the Lancaster University's North-West England Hydro Resource Model and the United Nations Development Programme's Derisking Renewable Energy Investment model.

Its applicability to alternative renewable energy sources (primarily, solar and wind), different areas of the world (particularly, across Asia, Africa and the Americas) and various scales (e.g. small, medium, large) would be assessed to such understanding of the barriers to the deployment of renewable energy.

In comparison to other approaches reviewed, they provide an opportunity to fill knowledge gaps in the literature in the inter-disciplinary assessment of these barriers irrespective of the stage of development of a region or country.

The thesis emphasises the role of decision-makers, drawing on the author's own perspective from different standpoints: as a leader and adviser at multilateral institutions, as a developer and practitioner at multinational corporations, and as a researcher at multidisciplinary organizations, including Lancaster University.

The perspectives from different stakeholder viewpoints will show that the general public is not only subjects of acceptability, influence or decisions, but also human resources themselves. Research shows developing individual and institutional capacity, upskilling and reskilling the energy transition workforce and empowering leadership across renewable energy supply chains and ecosystems, research shows people can be the biggest barrier or enabler to renewable energy deployment.

1.3 Approach

1.3.1 Methodology

The thesis is the outcome of site visits, desk research and stakeholder insights throughout the 2013-2023 research period. The research covered renewable energy deployments in emerging markets and developing economies across the Americas (Caribbean and Latin America sub-regions), Africa (Sub-Saharan region) and Asia (Central region). These different contexts provided a comparison with renewable energy developments in OECD countries (including the UK, Europe and the United States). This section outlines the research methodology to assess the barriers to the deployment of renewable energy. It integrates these three mixed-methods research approaches (site visits, desk research, and stakeholder insights) grounded in case study analysis, comparative assessment, and model adaptation. It summarizes the criteria for site and data selection, addresses issues of data reliability and clarifies stakeholder engagement approaches, explaining how findings were synthesised, including limitations and COVID-19-related disruptions.

1.3.2 Site Visits

Countries were selected from the project sample the author was involved in – see chapters 2 and 3 (Sub Saharan-Africa), chapter 4 (Latin America), chapter 5 (Central Asia), and chapter 6 (the Caribbean), as aligned with the thesis research objectives, and the following criteria relevant for the application of the DREI and NWHRM:

- Geographic range (Sub-Saharan Africa, Latin America, Central Asia, Caribbean)
- Renewable energy source (hydropower, solar and wind power)
- Investment deployment scale (micro, small, medium, large)
- Country economic development category (EMDEs)

Initial research has focused on understanding hydropower investment dynamics, with some coverage of solar and wind RE technologies, and limited consideration of ocean, biomass and geothermal energy. Deployments included Tajikistan's and Paraguay-Brazil's Large Scale Hydropower, Namibia's Concentrated Solar Power, Panama's Wind Power, and Equatorial Guinea's "Sustainable Energy for All" projects. The following information was collected from the selected project documentation (e.g., project proposals, feasibility studies, performance data, and local energy plans), and on-site consultations with government officials, utility operators, NGOs, and private developers: (a) infrastructure and technological configuration (e.g., type of RE system, capacity, maintenance regime); (b) policy and regulatory context (e.g., energy laws, permitting challenges); (c) project development timeline, financial structure, and derisking mechanisms; (d) socioeconomic and environmental impacts (e.g., job creation, displacement, biodiversity).

Field visits during the research period have spanned across Africa (i.e. Mozambique, Zambia, South Africa, Equatorial Guinea); Latin America (i.e. Ecuador, Panama, Mexico, Bolivia, El Salvador, Honduras); the Caribbean (i.e. Grenada, St. Lucia, Haiti, Barbados); Asia (i.e. Tajikistan, Philippines, Thailand); and, Europe (i.e. Spain, United Kingdom).

Most visits were associated with investment projects implemented by the World Bank (WB), funded by its own capital and/or other sources (e.g. GEF-Global Environment Facility, CIF-Climate Investment Funds, amongst others), building on previous research of projects implemented by the United Nations Development Programme. They all provided relevant insights to the main research questions.

Based on the above evidence the research assessed the applicability of both NWHRM and DREI models. Site visits, desk reviews and related stakeholder engagements throughout the research period (2013-2023) support the basis for the adaptation proposals, while acknowledging the limitations and considerations for further analysis where applicable.

Field research helped validate and stress-test the relevance and adaptability of key parameters of the NWHRM (i.e., renewable energy potential, demand and economics, public acceptability, resource capacity, investment decision criteria) and the DREI model (i.e., risk environment, public instruments, levelized costs, evaluation), as applicable to different renewable energy sources, scales and sites

1.3.3 Desk Research

In addition to the literature review briefly summarized in the previous chapter, desk research included various methods to research barriers to deployment of renewable energy deployment barriers in EMDEs. Initial desk research has covered Africa (e.g. Sao Tome & Principe, Namibia); Latin America (e.g. Brazil, Chile, Colombia, Costa Rica, Guatemala, Paraguay, Uruguay); and, the Caribbean (e.g. Antigua & Barbuda, Dominica, Jamaica and St. Vincent & the Grenadines).

Data sources included peer-reviewed journal articles, government reports, policy papers, and industry studies related to renewable energy developments. Searches included the use of academic databases such as Scopus, Web of Science, and Google Scholar to conduct reviews, explore findings and assess knowledge gaps that the thesis could address.

Case studies of specific projects provided a deeper exploration of renewable energy technology applications in specific countries and regions. These involved the collection of secondary data from international organizations (e.g., United Nations, World Bank, International Finance Corporation, African Development Bank, International Renewable Energy Agency, Sustainable Energy for All, Inter-American Development Bank, Rocky Mountain Institute, Asian Development Bank) and multilateral climate funds (e.g., Global Environment Facility, Climate Investment Funds or the Green Climate Fund). They were essential to understand the criteria and rationale for the provision of grant and non-grant fund mechanisms to renewable energy projects, which became a critical element to access climate finance through concessionary means (e.g., donations, subsidies, first loss capital, low interest loans and credits) that would help derisk deployments in EMDEs.

In addition, policy analyses and assessments of government and country reports, statistical databases, industry and market studies helped assess the enabling frameworks for renewable energy deployment (e.g., macroeconomic and fiscal conditions, human development, GDP growth, foreign direct investment, energy demand). These reviews of national and regional energy policies, regulatory frameworks, and international climate negotiations (e.g., Paris Agreement) helped assess whether policies were either conducive or hindering renewable energy deployment. It also offered the opportunity to compare policies across EMDEs and OECD countries to identify best practices and lessons learned. Reliability of data sources, and information collected through desk review was ensured by the selection and prioritisation of literature from the above institutions, which have well-established research methods, editorial policies and publication processes.

From the author's own experience, these literature references undergo comprehensive quality control and assurance steps, internal and external peer review stages before they are finally published. In addition, the author triangulated data across multiple sources for consistency and validated publication credentials, comparing and contrasting information with insights from stakeholders engaged before, during and after field research.

Any gap in knowledge was then identified through thematic analysis and bibliographic revisions of documentation provided by project partners and supplementary interviews. This was in line with the cross-regional and inter-disciplinary nature of the thesis and related data challenges (e.g., limited publicly available information in Sub-Saharan Africa, incomplete renewable energy datasets and project evaluations; language barriers and related technical jargon).

1.3.4 Stakeholder Insights

Engagement of energy decisionmakers, practitioners, policymakers and stakeholders of renewable energy deployments through semi-structured or unstructured interviews were essential to validate field visits and desk research. They were selected through purposeful sampling to include ministry of energy officials, project developers and financiers (incl. UNDP, IFC, WB staff), community leaders and local beneficiaries, academic and technical experts involved in model design and/or project design.

They helped gather detailed, nuanced insights into the challenges and barriers faced in EMDEs from key informants, including government officials, industry experts, NGO representatives, and academics. The use of open-ended questions to explore topics like regulatory hurdles, financing difficulties, and infrastructure constraints helped provide on-the-ground perspectives. It was part of semi-structured interview protocols, tailored to each type stakeholder, addressing core questions around real and perceived barriers to renewable energy deployment, effectiveness of derisking instruments and the applicability or limitations of sequential decision-making and derisking models such as the DREI and NWHRM.

The collection of such information was either part of the site visits, exchanging information with Lancaster University supervisors and other university researchers included in-person and on-line meetings, seminars, workshops and teleconferences through different means (e.g., via Zoom/Teams, by phone) depending on logistical feasibility. Interviews ranged from 30 to 90 minutes, and data was transcribed for analysis by common themes in the DREI and NWHRM components. Any discrepancies or contradictory statements were followed up where feasible.

Of note, at the beginning of the research period, when distance-learning was not a common doctoral study option, exposure to other researchers was limited, but this increased over the years before and after the COVID-19 pandemic.

Either way, interviews provided deep, qualitative insights and allowed the author to understand complex socio-political and economic factors that influenced renewable energy adoption.

Findings from the three data streams (site visits, desk research, interviews) were triangulated against critical model parameters (e.g., policy support, financial risk, community engagement), to identify convergence (e.g., common barriers such as lack of grid infrastructure) and divergence (e.g. context-specific nuances). The thesis adopts a critical interpretive approach, favouring first-hand stakeholder perspectives supported by secondary data.

Limitations addressed through this research approach included data access restrictions and unavailability (e.g., Equatorial Guinea) and interview logistics (e.g., COVID-19 disruptions). They imposed constraints on research and stakeholder availability resulting in lack of depth due to time constraints, which were mitigated by supplementing gaps with archival documents and institutional reports, expanding virtual stakeholder networks and extending the research period to allow more data collection post-COVID.

In summary, site visits provided real-world case data; desk research contextualised and supplemented field findings; and stakeholder insights added a critical qualitative dimension. The triangulation of these data streams enabled a robust examination of the applicability and limitations of the DREI and NWHRM.

2 Identification of Barriers to Renewable Energy in Equatorial Guinea Applying the North-West Hydro Resource Model

2.1 Equatorial Guinea "Sustainable Energy for All"

The NWHRM assessed barriers to small-scale hydropower developments in the UK that might be relevant for similar investments in developing countries. This chapter applies the model in an African context drawing lessons from UNDP's design, development and implementation of the Equatorial Guinea "Sustainable Energy for All" project funded by the Global Environment Facility (GEF)[1]. The chapter provides an overview of its approval process, barrier analysis performed at its design, and describes challenges and opportunities during implementation considering critical NWHRM areas. It ends with a comparison of barrier removal approaches, underscoring their potential relevance to different geographies.

The Equatorial Guinea "Sustainable Energy for All" (SEforALL) project was funded by the Global Environment Facility (GEF) and supported by the United Nations Development Programme (UNDP). The goal of the project was to create a market for decentralized renewable energy solutions in small island and remote territories by addressing the weakness of the country's policy-institutional, market and technology supply frameworks (GEF, 2013b).

The project was set to tackle the root causes of the barriers to renewable energy utilization in the country through four key components: (1) Clean energy planning and policies for implementation and scaling up; (2) Clean energy technology (hydro) demonstration; (3) Clean energy technology (solar) demonstration; (4) Clean energy knowledge and capacity development.

As a result, the project was expected to generate global benefits in directly avoided greenhouse gas (GHG) emissions of almost 1,780 kilotons of CO2 due to switching from fossil fuels for power generation to small hydro, solar PV and wind power (over the lifetime of 20 years) and an estimated 7,121 0ktCO2 as indirect emission reduction impact (GEF, 2013b). It sought to address barriers

[1] GEF (2013a) Equatorial Guinea - Sustainable Energy for All.

for any renewable energy technologies, but it focused on hydropower developments in the small island of Bioko and remote territories part of the Congo Basin.

2.1.1 Country Overview

The Republic of Equatorial Guinea a small West-Central African country with an area of 28,000 km2 and a population of around 720,000[2]; an insular region off the Gulf of Guinea, which consists of the islands of Bioko (with the nation's capital city in Malabo) and Annobón (a small volcanic island south of the equator); with its continental region, Río Muni, between Cameroon and Gabon, which also includes small offshore islands such as Corisco (see *Figure 12*, below):

Figure 12: Equatorial Guinea Map

Source: UNEP (2016)

According to the World Bank (2013), since significant offshore oil discoveries were made in the Gulf of Guinea in the early 1990s, oil became Equatorial Guinea's most important export (75% of revenues came from crude petroleum, 22% from liquefied hydrocarbons); its fossil-fuel economy accounted for 95% of Equatorial Guinea's Gross Domestic Product; the country thus enjoyed the

[2] WB (2013) Africa Development Indicators 2012/13

highest gross national income per capita (USD 13,720) of any other Sub-Saharan country in 2010, at the beginning of the 2013-2023 thesis research period.

According to the United Nations Environment Programme[3], the country's total electricity production in 2015 was 82 ktoe with 57.3 per cent generated from hydro and 41.4 per cent generated from fossil fuels, and electricity consumption 36 ktoe; its national electrification rate in 2012 was 66 per cent; 43 per cent of rural areas are electrified and 93.1 per cent of urban areas. The electricity sector is a major focus of the national development strategy.

Its national development strategy 2020 committed Equatorial Guinea to providing the country and its population with basic needs for development.[4] The country's "Electricity for All" statement aims to establish an efficient and reliable electricity system. Fifty-five per cent of the national population uses modern fuels. When disaggregated by location, only 25 per cent of the rural population uses non-solid fuels compared to 91 per cent in urban areas. The share of renewable energy in the total final energy consumption has been decreasing steadily since 1990 to 29.2% in 2012 (traditional solid biofuels form the biggest share of renewable sources, 29%, with hydro contributing only 0.8%).

Both ministries of Mines and Hydrocarbons, and Industry and Energy are in charge of the energy sector. The electricity sector is operated by Sociedad de Electricidad de Guinea Ecuatorial. The legal framework is provided by the country's Fundamental Law, with provisions on energy, but the main sector policy is contained in the Hydrocarbons Law.

The country's Initial National Communication and its Nationally Determined Contributions to the UNFCCC Paris Agreement focus on identifying mitigation options suitable to the country, in line with global initiatives such as Sustainable Energy for All, national development and energy policy frameworks (NESDP Horizon 2020-2035, National Electrification Plan).

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[3] UNEP (2016)
[4] EG (2008)

2.1.2 Project Profile

Equatorial Guinea's "Sustainable Energy for All: Promoting small-scale hydropower in Bioko and other clean energy solutions for remote islands" project is funded by the Global Environment Facility and supported by the United Nations Development Programme.

The goal of Eq. Guinea's SE4ALL project is to create a market for decentralized renewable energy solutions in small island and remote territories, addressing the weakness of the country's policy-institutional, market and technology supply frameworks and tackle the root causes of the barriers to RE utilization in the country.

The project consists of the following components: (1) Clean energy planning and policies for implementation and scaling up; (2) Clean energy technology (hydro) demonstration; (3) Clean energy technology (solar) demonstration; (4) Clean energy knowledge & capacity development.

The project is expected to generate global benefits in directly avoided greenhouse gas (GHG) emissions of almost 1,780 kilotons of CO2 due to switching from fossil fuels for power generation to small hydro, solar PV and wind power (over the lifetime of 20 years) and an estimated 7,121 ktCO2 as indirect emission reduction impact. The SE4ALL project was conceived to help the Government address climate change, amidst the country's dependence on fossil fuels (oil and gas).

2.1.2.1 Project Barriers

Equatorial Guinea has significant renewable energy potential. The vast majority of its total RE installed capacity comes from hydropower plants.

The power capacity has improved with the commissioning in October 2012 of the Djibloho hydroelectric plant (120 MW), so generation capacity now stands at 385 MW. Although largely undeveloped, Equatorial Guinea is estimated to have 11,000 MW of hydropower potential, of which 50% is deemed economically recoverable. However, small-scale hydropower has received little attention.

For example, in the south of Bioko Island, the old 3.8 MW hydro plant in the town of Riaba has been operating at times at 2% of capacity due to lack of investment in maintenance and need of refurbishing, despite increasing economic activity from the nearby freeport in Luba. The challenges behind this lack of investment, as identified at the start and mid-way through the SE4ALL project implementation, include barriers of a political, technical and financial nature detailed in Table 2 (below).

Within the framework of development plan, Horizon 2020-2035 and National Electrification Plan the country is primarily focusing on:

- Taking advantage of the large hydropower in the mainland – the Djibloho power plant represents the first of a series of long-term planned large-scale hydropower facilities along the Wele River in continental Equatorial Guinea (Río Muni) for which various large-scale, 200-400 MW-size hydropower schemes are planned at an estimated total of 2,000 MW;

- Increase of power generation capacity on Bioko Island – by means of adding new plants based on fossil fuels, expanding and upgrading the distribution and transmission network;

- Rehabilitation of the existing small hydropower plants – on Bioko Island (Riaba, Musola) and the mainland region (Bicomo), adding new small hydropower capacity, as well as development of the solar (and wind) resource (in particular on the remote island of Annobón);

- Institutional and capacity improvements – including the introduction of a new Energy Law and restructuring of the power company SEGESA; and, technical capacity building of staff in the power sector by establishing a School for Electricity within the National Technological Institute ITNHGE.

Currently, the insular regions continue to rely almost 100% on fossil-fuel based electricity. However, given SEGESA's problems with providing reliable power, small hydro may continue to merit attention.

The project was set to support such developments, along the planned refurbishment of the Riaba (4 MW) and Bicomo (3.2 MW) plants, and of the micro hydro facilities Musola 1 and 2 (totalling 0.4 MW). The feasibility study on the development of the hydropower potential of the Ilachi River (10-15 MW) in Bioko was also part of those developments, along with a solar-diesel hybrid system (with 5 MW solar) at Annobón Island.

The next stage would be to upscale grid extension and transmission to further expand electrification to remote rural areas, to link up with the power system of neighbouring countries (CAPP, Central African Power Pool) as well as ultimately a submarine power line interconnecting Bata and Malabo.

Funding from the Global Environment Facility was sought to support these activities, and to create an enabling environment for future investments in renewable energy, addressing a range of barriers exist to the use of solar, wind and small hydropower, as outlined in *Table 2* below:

Table 2: Equatorial Guinea SE4All Project Barriers

Barrier description	Baseline situation or action	GEF-supported alternative Incremental reasoning
Regulatory and policy barrier		
Lack of RE strategies and plans for off-grid island and hinterland remote areas: • Energy policy decision-making processes primarily focus on oil and gas developments, while in the power sector the focus is primarily on larger scale, grid	• Apart from the electrification plan, there is no longer-term RE or off-grid electrification section or separate plan; • On-going large hydro developments, and Initial National Communication to the UNFCCC (in progress), are barely advancing the climate	*Legal/policy provisions accommodate for smaller scale, decentralized solutions (e.g. small hydro, solar, wind), appropriate for each location and considering sustainable development concerns (e.g. employment generation, rural women).* **Outputs:**

Barrier description	Baseline situation or action	GEF-supported alternative Incremental reasoning
extension and transmission concerns. • Subsidized petrochemical products do not reflect the actual cost of fuel-generated electricity, deeming RETs expensive	change mitigation agenda.	1.1 Approved policy de-risking framework integrated resource planning and RE action plan
• Lack of procurement and licensing processes for (independent) power production in Equatorial Guinea) • Thus, limited scope for RET entrepreneurship and for IPP in general	• The monopolistic context in the power sector with no incentive for small scale electricity generation and distribution leads to a small market for RETs; • Plans of restructuring of SEGESA foresee splitting its functions of grid operator and distributor; next stage would see its privatization and the establishment of an independent regulatory authority for the sector; as well as introducing a more rational power tariff system	1.2 Accepted and implemented procedures for RE projects assessment and approval
Institutional / Technical / Economical:		
Limited institutional	• Lack of local skills and	*Capacity building processes*

Barrier description	**Baseline situation or action**	**GEF-supported alternative** **Incremental reasoning**
capabilities and local skills to embrace RETs: ▪ Limited hydropower, solar or wind energy expertise in Equatorial Guinea's MMIE and MFE; No or limited coverage of climate mitigation concerns within the curriculum of the National Technology Institute ITNHGE ▪ Inexistent technical capacity in the supply side (suppliers, installers, financiers) and limited hydropower maintenance capabilities (incl. administration and lack of accountability over asset integrity)	practical experience with small-scale RETs continues; • Lack of information on the costs and benefits of renewable energy sources and appropriate business models	*address local individual and institutional technical development needs (e.g. solar PV, hydro), awareness raised on their benefits, and integration of RE in the curricula of ITNHGE. MMIE embraces climate mitigation in the reshuffled SEGESA management.* **Outputs:** 4.1 Awareness raised amongst decision-makers in public and private sector. 4.2 Training programs on RET established and technicians trained
Market / informational / financial:		
Lack of awareness and information on the benefits of renewable energy sources in Equatorial Guinea • No knowledge of clean energy	• National utility (SEGESA) is in the process of rehabilitation of the small hydropower plant at Riaba (3.8 MW) and the micro hydro Musola (2 facilities of 0.5 MW	*Government is informed by techno-economic considerations, as appropriate for smaller scale and higher maintenance hydro plants (e.g. river flow estimates,*

Barrier description	Baseline situation or action	GEF-supported alternative Incremental reasoning
(particularly, solar and wind) resource endowments in Equatorial Guinea; • High upfront costs (augmented by custom duties) remain further impairing the cost of introduction of RETs in a small market (no economics of scale);	located in the south of Bioko island), but it is unclear that technical and economic feasibility and environmental considerations are met in the current rehabilitation activities or how can be translated in a feasible business plan for administration, operation and maintenance; • Plans for solar project on Annobón (up to 5 MW) with the American MAECI Solar	*turbine type, head size), and corresponding environmental conditions of the south of Bioko Island (e.g. aquatic life, riparian flora, dry season)* **Outputs:** 2.1 Resource assessment and pre-feasibility for small hydro (Ilachi, 12 MW, and other) 2.3 Completed pilot project demonstrations of rehabilitated (Riaba, Musola, Bicomo; 7.6 MW) and new small-scale hydropower plants. 3.1 Feasibility and business plan for solar (Annobón) and resource and pre-feasibility assessments (solar for remote/rural villages) 3.2 Completed pilot project demonstrations of solar at Annobón (5 MW) 4.3 Project impact assessment; dissemination of best practices and lessons learned.

Barrier description	**Baseline situation or action**	**GEF-supported alternative** **Incremental reasoning**
		4.4 Monitoring and evaluation
Economic / investment decision		
No economies of scale and scope identified to leverage RE small investments. • No consideration of innovative financing mechanisms for RE developments (e.g. feed-in-tariffs, carbon finance); • General poor framework for foreign investment, impairs investments in RE	• Available public funds from oil and gas revenues bankroll nationwide infrastructure developments, including small hydropower, solar, and wind**)**. UNDP and MMIE interface with oil and gas players on social contributions targeting clean energy (e.g. Noble Energy); this may be replicated by other operators that dominate the hydrocarbons market (mainly US companies, such as ExxonMobil, Marathon Oil, Hess; although European and Chinese companies are increasingly active and providing significant credit lines)	*GEF funding of de-risked policy, business and institutional environment, leads to the promotion of on-grid and decentralized electrification (i.e., remote islands, isolated hinterlands, rooftop), and sustainable development gains (e.g. employment, local content, gender empowerment).* **Outputs:** 2.2 Completed business plan for Ilachi (with detailed feasibility, environmental impact analysis and detailed technical design) 1.3Endorsed financial de-risking measures to implement innovative public and private funding options for recommended small hydropower, solar and wind in small islands; 4.3 Project impact assessment; dissemination

Barrier description	Baseline situation or action	GEF-supported alternative Incremental reasoning
		of best practices and lessons learned; 4.4 Monitoring and evaluation

Source: Author's contribution to GEF (2013a)

Each of these barriers had distinct implications for renewable energy deployment in Equatorial Guinea, playing a role at different stages of the renewable energy life cycle—from project design, financing, and permitting, to construction, operation, and scaling up. Table 2 (above) connects the technical, economic, regulatory, and social aspects into a holistic understanding of what must be addressed to successfully deploy renewable energy in similar EMDEs, as many of these barriers were interconnected. For instance, lack of policy led to poor investment climate; lack of skills resulted in poor maintenance and reliability; and lack of awareness suppressed public support and adoption.

Firstly, with regards to regulatory and policy barriers, lack of renewable energy strategies and plans for off-grid areas had a negative impact since without clear strategies, energy planning was reactive and heavily skewed toward fossil fuels. The absence of specific targets, timelines, or implementation frameworks discouraged investor confidence and made project initiation cumbersome. This barrier reflected a systemic policy vacuum, which hindered national alignment with global climate commitments (e.g., Equatorial Guinea's Nationally Determined Contributions under the Paris Agreement), delayed energy planning processes, and prevented resource prioritization for decentralized renewables.

Also, the existence of subsidized petrochemical products made fossil fuels appear cheaper than renewable energy due to subsidies, distorting the market and making renewable alternatives seem economically unattractive. This created a false economic narrative that undermined renewable energy competitiveness, when levelized costs of energy (LCOE) for solar or wind are dropping globally. In addition, the absence of procurement and licensing processes for independent power producers (IPPs) discouraged private sector participation in renewable energy development. The lack of enabling legislation severely restricted market liberalization and slowed down the creation of competitive renewable energy ecosystems.

Secondly, with regards to institutional, technical, and economic barriers, with limited institutional capabilities and local skills, ministries and utilities lacked expertise in renewable energy technologies. Capacity gaps at the National Technology Institute for Hydrocarbons further weakened the pipeline of skilled professionals. This gap led to technical dependency on external consultants and vendors, raising costs and diminishing long-term sustainability and local ownership of projects. In addition, weak supply chains and maintenance capacity together with lack of skilled technicians meant systems suffer from downtime and inefficient operation (e.g., the Riaba hydro plant operated at only 2% capacity). This affected operational reliability and eroded public and investor confidence in renewable energy systems, especially in remote or island areas.

Thirdly, with regards to market, informational, and financial barriers, the lack of awareness of renewable energy benefits meant that government agencies, the public, and even utilities did not fully understand the cost savings, resilience benefits, or emissions reductions associated with renewable energy sources. This fostered misperceptions and resistance, slowing demand creation and limiting policy advocacy for clean energy transitions. Meanwhile, with lack of resource mapping or feasibility data on solar irradiation or hydro potential, developers and financiers were unable to make informed investment decisions. This created a high-risk perception, leading to under-investment and the failure of lack of bankable renewable energy project pipelines.

In addition, with regards to high upfront costs and small market scale, high import tariffs and small market size meant economies of scale were not realized. This made renewable energy equipment and installation disproportionately expensive, which undermined their cost-effectiveness and deterred both public and private investment, especially in microgrids and off-grid solutions. Adding to this, the absence of innovative financing mechanisms meant that without feed-in tariffs (FiTs), concessional loans, or guarantees, renewable energy projects struggled to attract affordable finance. This resulted in capital rationing and a high cost of capital, especially problematic for first-mover projects or those in fragile environments.

All in all, there was a weak investment climate, with restrictive policies, lack of investor protection, and opaque regulations deterring foreign investors. This deprived Equatorial Guinea of access to climate finance, technological innovation, and project development experience from international partners.

2.1.2.2 Project Strategy

The project was in line with Equatorial Guinea's goal of provide access to energy to its entire population, while at the same time lead to the avoidance of greenhouse gas emissions, not often the priority of Least Developed Countries. As such the project was set to promote a reduced dependence on fossil fuel-generated electricity solar and wind power). The goal was to create a market for decentralized renewable energy solutions in small-island and remote territories with:

1. Clean energy planning and policies for implementation and scaling up - Outcome: Implementation of an approved clean energy enabling framework and mechanisms established for scaling up and replication of investment in on/off-grid, with these results:

1.1 Approved policy de-risking framework integrated resource planning and RE action plan

1.2 Accepted and implemented procedures for RE projects assessment/approval (e.g. PPA, FiT)

1.3 Endorsed financial de-risking measures to implement innovative public and private funding options for recommended small hydropower, solar and wind in small islands

2. Clean energy technology (hydro) demonstration - Outcome: Hydro energy technology and business model demonstrated in Equatorial Guinea's main insular and mainland regions, as follows:

2.1 Resource assessment and pre-feasibility for small hydro (Ilachi, 12 MW, and other)

2.2 Completed business plan for Ilachi (with detailed feasibility, environmental impact analysis and detailed technical design)

2.3 Completed pilot project demonstrations of rehabilitated (Riaba, Musola, Bicomo; 7.6 MW) and new small-scale hydropower plants

3. Clean energy technology (solar and wind) demonstration - Outcome: Other clean energy (solar) technology and business model demonstrated in the insular region, as follows:

3.1 Feasibility and business plan for solar (Annobón) and resource and pre-feasibility assessments (solar for remote/rural villages)

3.2 Completed pilot project demonstrations of solar at Annobón (5 MW)

4. Clean energy knowledge and capacity - Outcome: Information and knowledge on sustainable energy solutions widely shared; and clean energy technical, individual and institutional capacity strengthened, with these results:

4.1 Awareness raised amongst decision- makers in public and private sector

4.2 Training programs on RET established and technicians trained

4.3 Information dissemination and awareness creation of the general public

4.4 Project impact assessment and lessons learned reporting

4.5 Monitoring and evaluation

The project was set to deliver considerable global environment benefits in terms of GHG emission reduction through, fuel switching by replacing fossil fuels with renewable energy. The GEF contribution of USD 3,502,968 will result in a cumulative emission reduction of 1,781 kilotons of CO2 from the pilot/demo project in Components 2 and 3:

- Rehabilitation of small hydropower plants at Riaba, Musola and Bicomo (7.6 MW) – The mini facilities Musola I and II required a complete overhaul, including repairing damaged civil works, cleaning up the intake, canal and forebay of debris and silt particles and repairing the penstock, as well as providing repair and maintenance to the electromechanical equipment (turbines, generator, transformer). This will include carrying out a set of test and trial runs, obtaining the necessary spare parts and equipment as well as identifying, selection and training of the plant operators. The activities have started with cleaning up and repairing the civil works part. Similar type of overhaul and maintenance activities are planned for Riaba and a 33 kV transformer and transmission line is needed to connect the plant to the nearby town of Riaba. The nominal capacities are 3.8 MW (Riaba) with an estimated capacity factor of about 40% and 0.5 MW (Musola) with an estimated capacity factor of 55%, if fully functioning. On the mainland region, the existing small hydropower facility at Bicomo (3.2 MW) will be made operational in order to function again at maximum capacity;
- Small Solar-diesel hybrid systems on Annobon Island (5 MW) – The population of Annobon is about 5,000; other power demand categories

are public lighting (400 lighting points) and services (radio station, airstrip, clinic, and school). Demand could be supplied by a diesel-solar hybrid system, consisting of a solar PV facility (5 MW capacity), supplemented by a 10 MW diesel generator. Average daily irradiation on Annobón is 5.85-6.2 kWh/m2/yr, thus a 1 MW system could yield 4215-4515 kWh/day (capacity factor of 18%). A 5 MW solar project has been proposed by MAECI Solar (United States). A least 10 local residents will be trained so that they can maintain the installation in the future., 12 MW is assumed for the pilot project calculations here, assuming the employment of two Pelton turbine groups of 6 MW each;

- Small hydropower facility at Ilachi on Bioko Island (12 MW) – The assessment of the hydro-energy potential of Ilachi River (on South Bioko), design, feasibility and social-environmental impact assessment and subsequent procurement of equipment and installation. Part of these technical assistance cost will be covered by the GEF grant, while the remainder and cost of equipment is part of the co-financing. A first estimate of the plant's gross power production follows from rho*Q*g*h = 14 MW, based on the height (h) = 200 metres and a river flow of at least 7 m3/second. Depending on the season (rainy or dry), gross power availability could be up to 18 MW. Conservatively, 12 MW is assumed for the pilot project calculations here, assuming the employment of two Pelton turbine groups of 6 MW each.

The project investments were expected to translate into a GEF (direct emissions reductions) abatement cost of USD 2.25 per tonne of CO2, based on its cost effectiveness analysis.

2.1.2.3 Project Stakeholders

The project was designed to be executed by the Ministry of Fisheries and Environment (MFE), according to UNDP's National Implementation Modality, implemented by the Ministry of Mines, Industry and Energy (MMIE), with the national electricity utility (SEGESA), as the responsible party for the operation and maintenance of the power installations.

The Project Board was set up to include Ministry of Foreign Affairs (MFA), the Ministry of Fisheries and Environment (MFA), and UNDP to ensure the resources are committed and issues within the project are addressed, through proper coordination and communication with stakeholders.

The MFE was tasked to designate a senior official as the National Project Director (NPD), responsible for overall guidance to project management, adherence to the Annual Work Plans (AWP) and achievement of planned results as indicated in the Project Document. The NPD needed to ensure coordination with various ministries and agencies, provide guidance to the Project Management Unit (PMU), review reports and ensure oversight.

The Project Steering Committee (PSC) was established to provide strategic direction to the project, quality assurance to project monitoring and evaluation, and accountability for performance improvement and learning. The PSC could also consider and approve quarterly plans based on annual work plans, and approve any essential deviations from the original plans. The PSC was designed to include broad representation of key ministries, agencies and partners to the project.

Meanwhile, a small PMU was designed to coordinate the project's day-to-day operations with all stakeholders (especially, MFE, MMIE and SEGESA), report on implementation progress and be composed of the following staff: (a) full-time Project Manager, (b) full-time Project Administrative Assistant, (c) part-time Chief Technical Advisor, and (d) part-time Technical Experts. The PM is the primary project contact person and convener, responsible for delivery of results, with UNDP tasked to provide overall guidance, as responsible for the project's M&E. The project stakeholders include the following government counterparts, development partners, donor and grant providers:

- MFE – Main government partner with mandate over Equatorial Guinea's environment and fisheries policy, responsibility over its implementation, and national interface with the GEF

- MMIE – Key government partner with mandate over Equatorial Guinea's oil, gas and electricity policy, amongst others (e.g. mines, quarries) and responsibility over its implementation

- SEGESA – Key project implementing partner as the single electricity provider in Equatorial Guinea, tasked to undertake the planned investments, and seek financing for new RE projects.

- Other Ministries – that would participate in the Project Steering Committee and provide guidance on linkages with small RE and their respective field of action, e.g. agriculture, tourism, infrastructure, trade, economy and finance, industry, etc.

- European Union – as potential partner through the ACP-EU Energy Facility.

- China – business relations with Equatorial Guinea that may lead to additional development finance; and may also involve the engagement of SynoHydro corporation (Chinese hydropower developer).

- Private sector – Local and international construction, hydropower and service companies expected to support planned installations, related infrastructure works and service demands.

- NGOs and academia – Friends of Nature and Development of Equatorial Guinea (ANDEGE); the Program for Protection of the Biodiversity of Bioko (BBPP), the National University of Equatorial Guinea (UNGE), and the Council of Research, Science and Technology of Equatorial Guinea (CICTE).

The project concept was approved in March 2013, and full project document endorsed by the GEF CEO in December 2015. The Project Document was signed-off in March 2016 with an inception workshop and launch set for July 2016. Though actual implementation was delayed to September 2017, its MTR remained set for 2019 and closure/evaluation for 2021.

2.2 SEforALL Field Visit

The author assessed the Equatorial Guinea SEforALL project barriers both at project start and mid-term review (MTR) stages, the latter providing evidence-based, credible and reliable information. He led a collaborative and participatory approach, to ensure close commitment with the Project Team, government counterparts (including the GEF Focal Point), national stakeholders (including NGOs and academia), and GEF implementing agency (United Nations Development Programme), as follows:

1. Desk review of Project Document / GEF Documents / UNDP Documents covering project design, implementation progress, monitoring, national strategic and legal documents.

2. Face-to-face consultations with a wide range of stakeholders, using "semi-structured interviews" with a key set of questions in a conversational format. The questions asked aimed to provide answers from stakeholders vital to a successful MTR, including but not limited to triangulation of results, comparing information from different sources, such as documentation and interviews, and interviews on the same subject with different stakeholders to corroborate the reliability of evidence.

3. Direct observations of project results and activities at a selection of field sites, with particular focus on remote locations, including but not limited to the Riaba river and hydropower plant or the Musola river and mini-hydropower plants in Bioko Island, engaging key project stakeholders

2.2.1 Market Creation

For the creation of a renewable energy market, the author assessed that the SE4ALL project needed to build on the regulatory developments and existing capacities to respond to the lack of current results.

The project contributed to the development of the Energy Law and the Renewable Energy Regulation. However, their pending approval was relatively beyond the project's control.

Studies carried out to date (e.g. Ilachi River) showed that the investments required to undertake small-scale hydroelectric developments required greater resources (time, money) than initially expected. The main result achieved was associated with the rehabilitation of the Bikomo power plant, but the development of wind and solar energy remained far from materialization in the remainder of the project's life.

Further private capital participation would be required to catalyse additional resources considering limited public finance. Given their in-country presence, partnerships with the hydrocarbons industry could be transformational as complementary enablers of renewable energy deployment. By aligning financial, technical, infrastructure, and sustainability goals, such partnerships could help reduce upfront costs, build local capacity and enable long-term sustainability, thereby accelerating Equatorial Guinea's clean energy transition, as follows:

(a) Leveraging financial capital – The country's hydrocarbons industry had historically generated significant revenues that underpinned public infrastructure investments. This same industry could have been a catalyst of renewable energy deployment, with public funds derived from oil and gas revenues strategically redirected to seed renewable energy. Given oil companies such as ExxonMobil operated under production-sharing agreements with corporate social responsibility provisions, they could co-finance pilot projects in off-grid or underserved regions, fund grid extension projects that link renewable generation to existing load centres or absorb first-loss from these investments.

(b) Creating market conditions – Equatorial Guinea lacks enabling infrastructure for renewable energy deployment, with the power sector characterised for its monopolistic structure (i.e. run single-handedly by state-owned SEGESA). Private sector actors could help: co-develop shared infrastructure (e.g., substations, storage systems) for both fossils-fuelled and renewables-based operations, particularly in island and remote regions; pilot smart-grid and battery systems to stabilize grids to address intermittency issues of renewable energy integration; stimulate demand for renewable energy generation (e.g., mini-/micro-grid powering onshore services, logistics and infrastructure.

(c) Building skills and capacity – Hydrocarbon companies possess advanced engineering expertise, logistics experience, and supply chain networks that could support renewable energy deployment. These include engineering firms with expertise in gas infrastructure that could assist in the design and installation of mini-hydro or solar-diesel hybrid systems; logistics infrastructure used in upstream oil operations (e.g., helicopter access, barges, transmission lines) could be repurposed to facilitate deployment in remote locations like Annobón Island. Such partnerships could address the country's limited technical and institutional capacity as a key a barrier to renewable energy uptake, filling gaps with skills, training and workforce development for local value and supply chain creation.

Considering that hydrocarbon companies faced increasing pressure from investors and regulators to demonstrate alignment with international climate targets, these partnerships would also help their corporate social responsibility and sustainability reporting. Neither the SEforALL project nor the GEF support was geared to tap into private sector capital. Consequently, the project had only reached about 15% of its final direct emission reduction goal of 1,718 ktCO2. The project fell short of its emission reduction targets as a result of the combination of technical, financial and institutional challenges underscored by this thesis.

Challenges ranged from incomplete rehabilitation of key small hydropower facilities (i.e. Riaba, Bicomo, Musola), which were not fully operational within the project timeframe, and thus did not lead to the climate change mitigation impact expected from increased renewable electricity generation (e.g., systems like Riaba were operating at 2% of their capacity due to lack of spare parts, outdated technology, and maintenance issues). Solar PV and hybrid systems (e.g. Annobón Island) had implementation delays due to logistical and supply chain disruptions.

Success in awareness-raising activities had already exceeded its objectives, with more events, campaigns and training than proposed at the end of the project. As a result of these dissemination efforts, particularly targeted to decision-makers, the final objective of indirect emissions (7,121 ktCO2) would have been reached to the extent that they informed the project's reorientation towards small-scale alternative investments (e.g. investment in solar developments throughout the country).

2.2.2 Project Execution

Project management and implementing partner challenges were also affecting the achievement of tangible results. The implementation of SE4ALL Equatorial Guinea started well, with key joint push from the Ministry of Fisheries and Environment and the Ministry of Mines, Industry and Energy (MMIE), with UNDP support at the start of the project.

However, the project then evolved more slowly, with changes in the structure of the ministries and the administration of UNDP, whose formal update in the institutional arrangements of the project was still pending at the time of the author's field visit.

The impact of the changes was evident in the lack of clarity in the project's national implementation modality, which in the end resulted in a greater dependence on the support of the GEF implementing agency (UNDP) than it was originally expected, given the lack of effective involvement of current national counterparts in decision-making management (eg procurement, monitoring, personnel, consulting, and adjustments).

The SEforALL project proposed several workforce development and institutional management improvements to strengthen its execution. On workforce development, proposals included: (a) technical training in renewable energy systems, to develop hands-on programs for design, installation, operation, and maintenance of small hydro, solar PV and hybrid-system technologies; (b) pilot demonstrations, such as Ilachi small hydropower and Annobón solar PV, to enable learning-by-doing for local engineers, electricians and entrepreneurs; (c) soft skills, with community engagement and project communication, as examples.

On institutional management, proposals included: (a) restructuring of national power utility (SEGESA), including functional unbundling of generation, transmission and distribution arms; (b) establishing a dedicated renewable energy unit within government; (c) monitoring and evaluation of performance and outcomes of these efforts, including digitization of asset management and maintenance logs and integration of national reporting systems with goals.

2.2.3 Risk Management

The project implementation lacked sufficient adaptive management to handle the impact of institutional changes, which delayed key decisions to reorient the SE4ALL project towards success. The sustainability of its results was largely dependent on the effective management of multiple risks.

At an environmental level, the risks of impact on the protected areas around the originally planned hydroelectric developments (eg Ilachi River, 12MW) required a decision on the reorientation to other alternative developments (wind, solar). However, the initial studies on the wind regime (e.g. Annobón 5MW) and solar (lower quality of irradiation in Bioko, due to the dust of the harmattan phenomenon, than in Equatorial Guinea's continental region), have not resulted in action plans to respond to the current energy isolation of Annobón, remote areas of Bioko, Corisco and the Rio Muni region.

At the socioeconomic level, the project was not responding to the energy exclusion of rural areas, and corresponding energy poverty and related gender issues. At the governance level, the mandates and institutional coordination were not clear (i.e. MIE, SEGESA, MAGBoMA, Ministry of Fisheries and water resources) and at the financial level, the fiscal context of the country at the time required greater openness to the private sector (interested oil and gas companies included).

The SEforALL project attempted to address risks through alignment with best practices and institutional reforms to avoid environmental disruptions, build capacity and enable governance reforms for long-term sustainability. But execution gaps, weak capacity and insufficient monitoring limited their impact. Environmental impact assessments were required for renewable energy installation but follow-up enforcement and monitoring were inconsistent. Awareness-raising and training programs were undertaken for local technicians, youth, and rural communities to improve social acceptance of new technologies, reduce vandalism, and enhance local involvement. The project supported the formulation of energy policies (e.g., renewable licensing guidelines and procedures), to strengthen governance and derisk investments.

2.2.4 Impact Sustainability

Despite the above challenges, the author assessed that the project continued to be aligned with the country's objectives. This was also the view of the relevant ministries, civil society and academia. While all stakeholders underlined the complexity of interministerial implementation, the expected results of the project could have driven MMIE's plans for renewable energy, MFE’s climate change agenda, and SEGESA's operation of a fossil-free energy matrix and network. However, like other EMDEs at the crossroads of the energy transition (for instance, Nigeria), Equatorial Guinea faced energy insecurity due to its dependence on fossil sources on the island of Bioko.

This dependence was also influenced by the limited energy matrix diversification in the rest of the national territory. Although the country had 80-90% of its energy matrix based on renewables, this source was concentrated in the continental region of the country (large-scale hydroelectric developments in Sendje and Djibloho).

In the insular region, however, 90% of the matrix depended on the Turbo Gas Power Plant in Punta Europa (150MW), which in case of failure would not have its renewable alternative. The exceptions were the sought after rehabilitation of small-scale hydroelectric plants (Riaba and Musola 4MW) or the potential of the Ilachi river 12MW is developed), which were supported by the SEforALL project. In any case, the installed capacity would have still been below the demand of Malabo, as the capital city, and without taking into account the demand of the urban districts that are sprawling around Bioko Island.

The remote areas of the continental region and other island regions (Annobón, Corisco) also needed diversified alternatives to face their situations of energy poverty, given the potential identified by the project for the development of distributed generation with solar thermal energy technologies and / or photovoltaic.

2.3 NWHRM Lens

Further to the author's field visit to Equatorial Guinea, the SE4ALL project would benefit from more implementation time to support the delivery of its expected results with existing GEF funding. With identified co-financing when the project was endorsed for implementation, hydropower and other potential renewable energy resource deployments in Equatorial Guinea would benefit from the assessment of some of the barriers identified from the viewpoint of the NWHRM. This was one of the various interventions the author had come across from his involvement in the project design (knowledge of potential, demand and economics), its development (public acceptability, resource capacity) and project inception for full implementation (decision to build).

2.3.1 Knowledge of Potential

One of the major gaps identified during the field research was the absence of hydrological and meteorological installations in the country. Lack of investment in infrastructure expected to be in place in the UK and other OECD countries, but only assumed present in EMDEs like Equatorial Guinea became a key constraint.

This gaps also influences the NWHRM work package associated to resource capacity to understand the energy and ecology implications of small and medium hydropower developments. It is one of the preliminary indications that in addition to deployment of infrastructure directly related to renewable energy generation, developing countries might need other enabling interventions.

2.3.2 Demand & Economics

The above reflection is relevant for what this NWHRM work package addresses: the identification of direct and indirect costs and revenues associated with renewable energy installations, and other losses and benefits for the community.

During the field visit, the author identified an additional source of funding beyond the GEF grants and government co-financing.

SEforALL had the potential to mobilize philanthropic capital and corporate responsibility donations from the country's development partners. Particularly the hydrocarbons sector would be a target for such mobilization. The extractive industries companies present in Equatorial Guinea have the capital and technology to support the country in its energy transition.

In its work experience prior to the renewable energy sector, the author became familiar with social investment obligations under oil and gas production sharing contracts. These are agreed and negotiated with government counterparts, and are a common feature of hydrocarbon deployments in EMDEs.

2.3.3 Public Acceptability

The project supported the preparation of the draft of the Energy Law, contributed to important renewable energy developments.

These positive developments included the Bikomo rehabilitation, pre-feasibility technical studies, and the sensitization of various partners towards climate change mitigation in a fossil-based economy. Yet one of the key barriers faced by the SEforALL project is the weaker buy-in by the government counterparts than at the beginning of implementation.

In addition to the additional time (1-2 years) and cofinancing resources (US$5-10 million), key to any renewable energy deployment was the need to rearrange the project’s institutional implementation. It needed the clarification and strengthening of roles and responsibilities, and the proactive and adaptive management of risks beyond any social resistance to the project.

Reactivate the project with its high levels in the MIE and MAGBOMA. It is necessary to reorient the project strategy so that the national counterparts have a useful and effective role. It is recommended to make a situational diagnosis of the project in order to reschedule it.

Update the project implementation mechanisms (organization chart, NIM). As in other UNDP-GEF projects at the global level, the project team could be installed in the office of the implementing partner (MAGBOMA) or responsible party (MIE) of the project, with the aim of strengthening the coordination and ownership of their national counterparts.

Strengthen the project management team in its key areas of operational deficiency. A chief technical advisor should be hired who can regularly oversee the technical deliverables, as well as strengthen the procurement area to streamline project management and processes.

Renew ties with the Ministry of Mines and Hydrocarbons to promote the energy transition. As the guardian ministry of private sector activities, apart from accelerating national co-financing, it has the ability to catalyze the mobilization of companies' resources, as part of their corporate social responsibility, or strategies for sustainable development, climate neutrality and social impact.

2.3.4 Resource Capacity

The author assessment includes a broader understanding of what the NWHRM considers resources. That is, renewable energy deployment would not only be contingent upon the identification of physical and natural resources to justify investment (hydrological infrastructure, water flow), but also human resources.

The field visit identified another barrier to the project success, such as the limited availability of a skilled workforce. Therefore, capacity development would also need to be strengthened with the inclusion of courses on renewable energy engineering and environmental careers. In parallel, decentralized renewable energy solutions would also need to be considered given the long lead times for on-grid, and utility-scale interventions.

In addition, institutional resource limitations would need to be addressed. These could include: technical advisory support for SEGESA, MMIE, and regulatory agencies; deployment of innovative financing mechanisms (e.g., feed-in tariffs, results-based finance, partial risk guarantees, blended finance); investment in nationwide renewable energy resource mapping and feasibility databases (e.g. GIS-based and software tools for solar irradiation, and hydro potential); human resource partnerships with technical schools and NGOs for skilling and training.

2.3.5 Decision to Build

The sustainability of the intended project impact was subject to follow-on investments, and alternative financing to the limited national and international public resources.

However, from the perspective of the NWHRM sequential decision making, the need to reactivate the project was key not only to secure buy-in, but advance in the decision to build. This would require leadership empowerment interventions beyond reskilling and skilling with the target of building the confidence to make such decisions.

This would require the update of the project implementation mechanisms, strengthening the project management team in its key areas of technical operational deficiency identified. The renewal of ties with the Ministry of Mines and Hydrocarbons would be key advance decision-making.

In retrospect, however, the SEforALL project built critical market-enabling foundations for renewable energy in Equatorial Guinea despite facing substantial barriers, and falling short of its emission targets, The achievements include:

(a) Policy and Regulatory Developments – Drafting of a National Energy Strategy with provisions for renewable energy, and of IPP frameworks and structures for future private sector engagement. Support for SEGESA reforms, initiating discussions on grid liberalization and unbundling, even if they were not executed.

(b) Pilot Projects and Infrastructure Investments – Commissioning small hydropower rehabilitation activities and piloting of hybrid solar systems; creation of proof-of-concept installations to scope, scale and validate feasibility.

(c) Skill and Capacity Development, and Awareness Raising – Training sessions for over 250 government staff, technicians, engineers, and energy planners;

public awareness campaigns that increased understanding of RE benefits among stakeholders, including policymakers and community leaders; establishment of a technical curriculum at the National Technological Institute (ITNHGE) incorporating RE topics to enable knowledge transfer.

3

3

3 Evaluation of Barriers in Sub-Saharan African Countries Applying the Derisking Renewable Energy Investment Model

3.1 Sub-Saharan African Context

The DREI original framework was applied to in Sub-Saharan Africa (SSA). The 2013 report included two SSA cases: South Africa and Kenya. The latter is not covered by the PhD thesis, but the author engaged their stakeholders on several occasions and country missions on a high-level, senior leadership capacity.

The former is covered next and draws on the author's several visits to South Africa on a technical-level, researcher and practitioner capacity. These engagements included education, participation and knowledge dissemination at energy and climate events (e.g., Association of Energy Engineers, Africa Wind Energy Association and Adaptation Futures 2018 conferences). They also included capacity building on developing UNDP-led, GEF-funded projects covered by the DREI report, and relationship building with relevant counterparts.

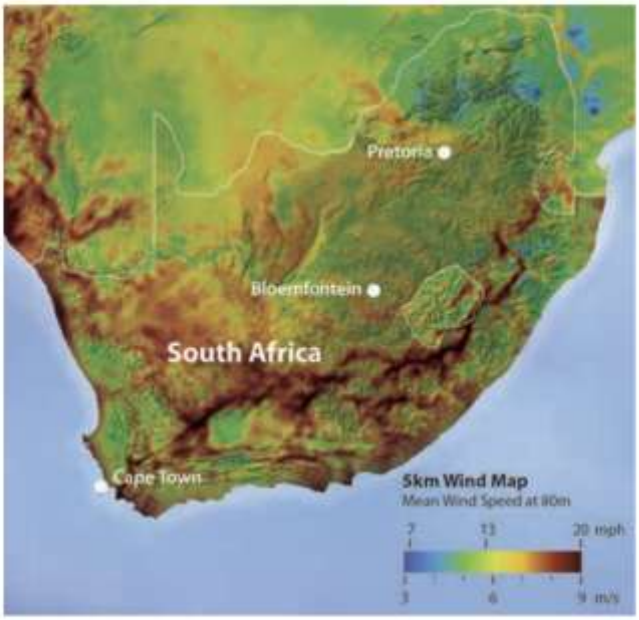
This exposure was critical for author's later development of another UNDP-GEF project, this time in neighbouring Namibia, where he lived for almost two years. The countries lend themselves to contrast and comparison, as the Namibian case was not included in the DREI report. As a result, the author seeks to identify additional barriers applying critical elements of the framework from scratch.

3.2 South Africa Onshore Wind Power

3.2.1 South African Overview

South Africa's peak electricity demand was approximately 36,500 MW supported by an installed capacity of 38,000 MW (90% coal-based) when the original DREI report was released; in 2010, the Government of South Africa set a target of 8.4 GW in wind energy investment by 2030 in its Integrated Resource Plan (IRP) to tap on South Africa's strong wind resources (UNDP, 2013). At the time, it had 10 MW of installed wind capacity across three pilot wind farms, which included a 3 MW Eskom pilot project commissioned in 2003 and a 5 MW donor-funded Darling demonstration project established in 2008 (ibid.). Drawing on South Africa's strong wind speeds at its Western and Eastern Cape coasts (*Figure 13*, below), the government issued a request for proposal in 2011 to attract interest:

Figure 13: South African Wind Map



Source: UNDP (2013)

The first round of the bidding process resulted in the selection of eight preferred bidders for a total of 634 MW of wind energy at an average price of ZAR 1.143 per kWh (USD 13.5 cents per kWh); the related power purchase agreements (PPAs) were signed in November 2012. The second bidding round, with submissions in March 2012, resulted in the selection of seven bidders for a total of 563 MW at a lower average price (ZAR 0.897 or USD 10.5 cents per kWh).

3.2.2 South Africa Risk Environment

The risk environment data was collected from interviews with six project developers, debt and equity investors exploring or actively engaging in wind energy projects in South Africa; general and country specific literature on wind investment barriers, cost of financing, risk probability and perceived financial impact from South African government officials, national wind association and development practitioners (UNDP, 2013). These assumed the opportunity to invest in 50-100 MW of wind with 2-3 MW class turbines from a quality manufacturer, build-own-operate business model, operations and maintenance contract, transmission lines within 50 km of the project site, and an engineering, production, construction sub-contract with non-recourse project finance (ibid.).

The following *Figure 14* (below) illustrates how investor risks contributed to higher financing costs for wind energy in South Africa, summarizing qualitative information gathered by the DREI case study from developers and investors:

Figure 14: South African Wind Investment Risk Categories

Source: UNDP (2013)

These risk waterfalls highlight power-market and currency, macro-economic risks as factors influencing finance costs, among others in Table 3 (below):

Table 3: South Africa Wind Energy Risk Categories

RISK CATEGORY	DESCRIPTION/EXAMPLES OF RISK
Power market risk	This risk category has a high impact on financing costs. On the positive side, investors comment favourably on many aspects of the regulatory framework. South Africa has a clear long-term 2030 target for wind energy in place. After a prolonged start, when the originally envisaged renewable energy feed-in tariff ('REFIT') was dropped, investors generally praise the replacement bidding process as well-defined and robust. The bidding process's stringent requirements on financing to ensure projects are commissioned is viewed positively. In terms of competitiveness, investors note that fossil fuel subsidies on electricity have been rolled-back in recent years, with end-user pricing rising significantly in this period. On the other hand, investors raise concerns in a number of areas. Some caution is expressed regarding Eskom's monopoly and a perception of past difficult experiences for fossil fuel IPPs to enter the market in South Africa. Some investors remark that tender processes can result in aggressive bidding and question whether current bids are sustainable. Investors also raise concerns regarding delays to the tender process. Looking ahead, investors note that it will be important for the government to closely monitor the development of the energy sector if it is to continue to maintain an effective regulatory framework going forward. Some investors expect local content requirements may become restrictive in later bidding windows.
Permits risk	This risk category has a moderate impact on financing costs. Investors generally view the licensing process with NERSA and other entities positively, noting good progress having been made in designing transparent, streamlined procedures, as well as in training staff specifically in wind energy. At the same time, some investors comment on a lack of coordination between entities issuing licences and permits.
Social acceptance risk	This risk category has a low impact on financing costs. Investors remark that public resistance to wind energy is low. They also note that the bidding process has trust-building requirements with local communities, with many communities holding stakes of up to 5 percent. Some investors, however, feel that social acceptance risk may increase overtime, particularly as wind farms become more widespread. Wind power can be perceived negatively as being expensive in comparison to coal-fuelled power.
Grid integration risk	This risk category has a moderate impact on financing costs. Investors comment that, after a mixed start, good recent progress has been made in coordinating with Eskom on this matter. NERSA has been regularly updating the grid code, which investors comment on as being realistic and suitable. The PPA has a 5 percent curtailment clause - investors note it is important that this is correctly priced into bids.
Counterparty risk	This risk category has a moderate impact on financing costs. The standard PPA is with Eskom, however Eskom's payments are backed by the Department of Energy. Investors are reassured by this government backing. Nonetheless, given the large long-term targets for renewable energy in South Africa, investors comment that counterparty risk remains, even at the sovereign level.
Financial sector risk	This risk category has a moderate impact on financing costs. South Africa has a large, developed financial sector, which has welcomed and engaged with wind-energy. The successful participants in the first bidding windows have obtained commitments for financing, in the most part from domestic banks. Given the large total investments needed to meet the long-term target, investors do express concern regarding lack of capital for investors participating in future bidding windows.
Political risk	This risk category has a moderate impact on financing costs. Investors are generally attracted by South Africa's stable political environment. Nonetheless, issues such as social inequality and good governance are identified as possible concerns.
Currency/ macro-economic risk	This risk category has a high impact on financing costs. The standard PPA for wind-energy is Rand-denominated and inflation-linked. Investors comment that this creates significant currency risk, particularly given the historical volatility of the Rand.

Source: UNDP (2013)

3.2.3 South Africa Public Instruments

In assessing the range of public instruments, the DREI case study noted that South Africa held an investment-grade rating; thus, financial derisking measures were deemed unnecessary. The package of policy derisking instruments considered had an estimated public cost of USD 40 million over the 2010-2030 modelling, and *Figure 15* (below) illustrated how these measures could be expected to lower financing (equity and debt) costs of South Africa wind energy:

Figure 15: South African Wind Post-Derisking Waterfall

Source: UNDP (2013)

The DREI modelling predicted that the policy derisking instrument package would cost around USD 40 million, and reduce the average cost of equity by 1.2%, and cost of debt by 0.5% over the 20-year period. This was based on in-house data and experience of renewable energy market transformation projects, i.e., estimating the public cost of design, implementation and evaluation, duration and assistance for each instrument based on the country's 20-year wind target, population, geographic size, electricity generation and status of policy activities; and, estimating the effectiveness of the policy instruments in reducing finance costs following stakeholder interviews with investors (UNDP, 2013).

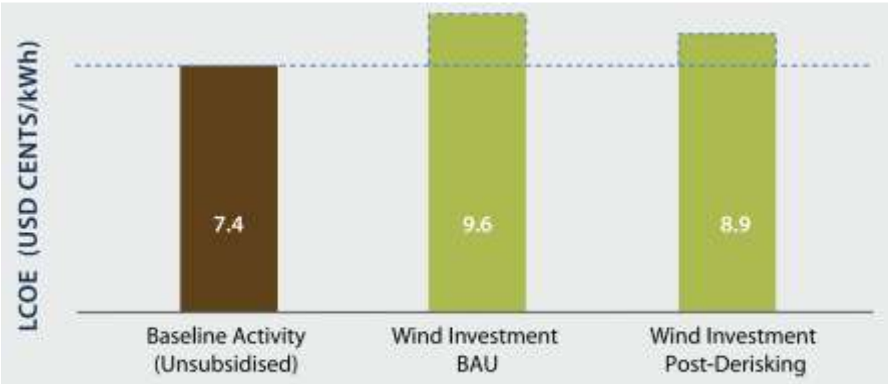
These were mostly focused on addressing the power market, counterparty as well as macroeconomic risks. The underlying barriers in South Africa included uncertainties over renewable energy targets, outlooks and strategies; prices, market access and competition; power purchase agreements and tendering procedures; utility (Eskom) credit rating, grid limitations and operational record.

While investors generally viewed South Africa's regulatory framework favourably (e.g., long-term target for wind energy by 2030, bidding financial requirements, fossil fuel subsidy reductions), they also raised concerns about Eskom's monopoly (i.e. entry challenges for independent power producers), procurement practices (e.g., aggressive bidding and tender delays, local content requirements) and the South African Rand volatility (i.e., standard PPAs denominated in local currency, linked to inflation).

3.2.4 South Africa Levelised Costs

Meanwhile, DREI model levelised cost of electricity results depicted in *Figure 16* (below) showed that wind energy is more costly (USD 9.6 cents per kWh) than the country's unsubsidized marginal baseline (USD 7.4 cents per kWh). The policy derisking package reduced the LCOE for wind energy from the business-as-usual (BAU) scenario to USD 8.9 cents per kWh in the post-derisking scenario:

Figure 16: South African Wind Power LCOE



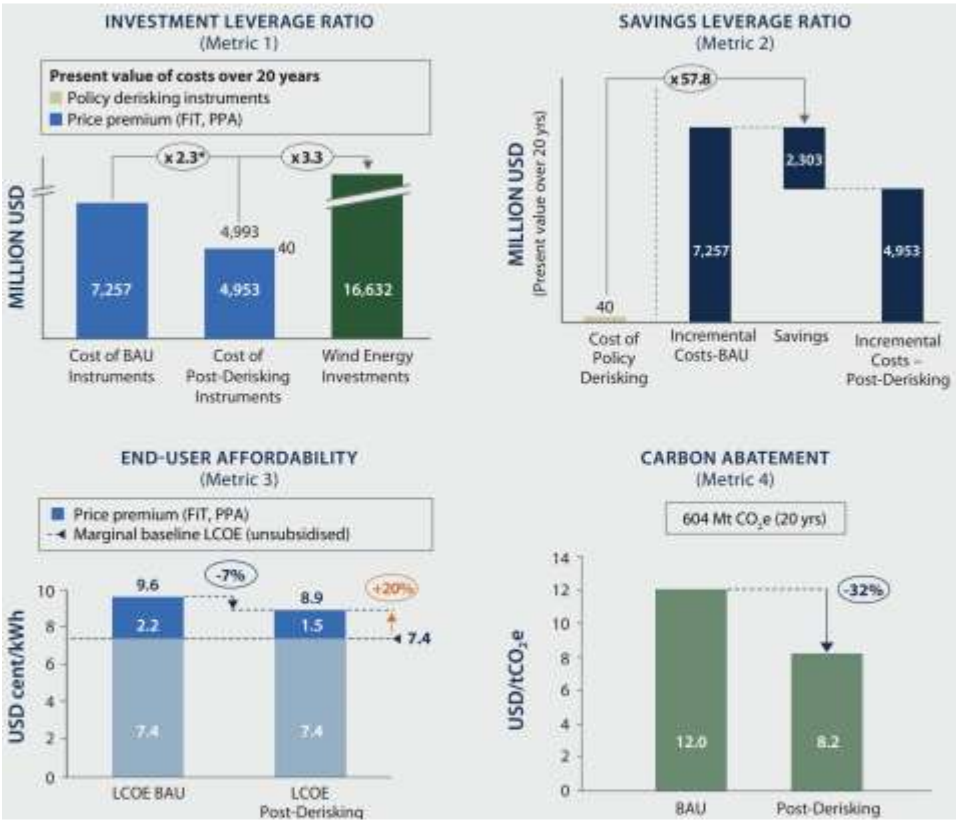
Source: UNDP (2013)

In both cases, the analysis indicates that a financial incentive is necessary to offset the incremental cost, and make wind energy competitive. Compared to the case study's model, the second window of bidders submitted an average price of USD 10.5 cents per kWh, which is higher than the BAU scenario price of USD 9.6 cents per kWh. This difference was partly due to the model selecting more favorable wind sites based on the assumption that transmission lines would be available. Additionally, the sensitivity analysis on the wind capacity factor demonstrated that a lower factor led to a higher LCOE in the BAU scenario.

3.2.5 South Africa Evaluation

Finally, the performance metrics of the DREI model South African case study, highlighted the potential of policy derisking to lower the financial incentives needed to support renewable energy in the country. In the BAU scenario, private sector investment in wind energy is expected at high costs. The investment leverage ratio for the BAU scenario was 2.3x, driven by the need for a direct financial incentive for wind energy (USD 7.3 billion over 20 years). The post-derisking scenario showed a savings leverage ratio of 57.8x, so USD 40 million worth of policy derisking instruments reduced financial incentives needed, saving around USD 2.3 billion over the same period –*Figure 17* (below):

Figure 17: South African Wind Power Metrics



Source: UNDP (2013)

Considering the related sensitivity analyses, which focus on the wind energy capacity factor and marginal baseline fuel costs – see *Table 4* (below), the affordability metric, which evaluates the incremental cost per kWh, showed that a 10% increase in the wind capacity factor under the post-derisking scenario would lead to a higher levelized cost of electricity.

It would also lead to a 54% reduction in the incremental cost, which shows the performance metrics of the DREI South Africa case study generally more responsive to changes in the wind capacity factor than to changes in fuel costs for the same percentage variation. This lower sensitivity to fuel costs was due to South Africa's relatively low baseline energy costs.

Importantly, the DREI modelling exercises researched would conduct two example sensitivity analyses for each country case study, adjusting one key input factor by +/- 10%, with two sensitivities: (a) *Wind energy capacity factor*, highlighting potential changes in wind speed, site selection, social acceptance, transmission line availability and turbine performance compared to the baseline; (b) *Unsubsidised fuel costs*, adjusting such costs over time vis-à-vis variations in the marginal baseline LCOE – see results in *Table 4* (below):

Table 4: South Africa Wind Energy Sensitivity Analysis

	SENSITIVITY ON WIND CAPACITY FACTOR						
	INVESTMENT LEVERAGE RATIO		SAVINGS LEVERAGE RATIO	AFFORDABILITY (INCREMENTAL COSTS USD/kWh)		CARBON ABATEMENT (USD TONNE CO_2e)	
Base case	BAU	2.3x	57.8x	BAU	$0.022	BAU	$12.01
	Post-Derisking	3.3x		Post-Derisking	$0.015	Post-Derisking	$8.20
+10% Capacity Factor	BAU	3.5x (50.6%)	57.8x (0%)	BAU	$0.013 (-39.6%)	BAU	$7.25 (-39.6%)
	Post-Derisking	6.5x (95.4%)		Post-Derisking	$0.007 (-53.8%)	Post-Derisking	$3.79 (-53.8%)
-10% Capacity Factor	BAU	1.7x (-25.1%)	57.8x (0%)	BAU	$0.033 (48.4%)	BAU	$17.83 (48.4%)
	Post-Derisking	2.2x (-32.8%)		Post-Derisking	$0.025 (65.8%)	Post-Derisking	$13.6 (65.8%)

	SENSITIVITY ON FUEL COSTS						
	INVESTMENT LEVERAGE RATIO		SAVINGS LEVERAGE RATIO	AFFORDABILITY (INCREMENTAL COSTS USD/kWh)		CARBON ABATEMENT (USD TONNE CO_2e)	
Base case	BAU	2.3x	57.8x	BAU	$0.022	BAU	$12.01
	Post-Derisking	3.3x		Post-Derisking	$0.015	Post-Derisking	$8.20
+10% Fuel Costs	BAU	2.7x (17.1%)	57.8x (0%)	BAU	$0.019 (-14.6%)	BAU	$10.26 (-14.6%)
	Post-Derisking	4.2x (26.9%)		Post-Derisking	$0.012 (-21.3%)	Post-Derisking	$6.45 (-21.3%)
-10% Fuel Costs	BAU	2x (-12.7%)	57.8x (0%)	BAU	$0.025 (14.5%)	BAU	$13.76 (14.5%)
	Post-Derisking	2.8x (-17.4%)		Post-Derisking	$0.018 (21.3%)	Post-Derisking	$9.95 (21.3%)

Source: UNDP (2013)

Overall, the DREI framework applied to South Africa focused on the promotion of large-scale, onshore wind energy drawing on a well-established renewable technology, with a strong track record and readily available data. The model relied on a simplified set of data and assumptions; therefore, the above outputs were presented as indicative of the case study, rather than definitive figures. These evaluation steps were undertaken by carrying out a sequential comparative analysis of the public instruments selected and sensitivity analyses.

The performance metrics required: (1) setting up a target renewable energy investment and assessing the cost of derisking instruments to achieve it, by comparing their net present values to compute the *investment leverage ratio*; (2) comparing the cost of derisking instruments vis-à-vis the savings resulting from deploying them to compute the *savings leverage ratio*; (3) calculating the impact of the public instruments on electricity consumers by comparing the generation cost (LCOE) of wind energy in pre- and post-derisking scenarios to arrive at the *end-user affordability*, and; (4) contrasting the carbon abatement potential versus the renewable energy investment, by dividing the present value of the incremental costs (in USD) by their climate change mitigation potential (in tCO_2).

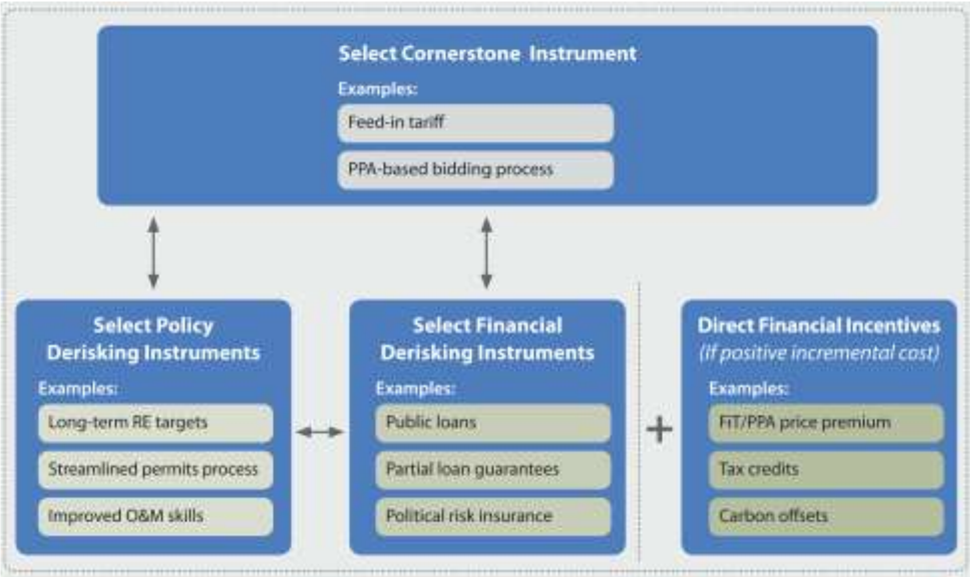
The sensitivity analyses assess the impact of a +/- 10 percent variation in both the wind energy capacity factor (i.e., indicative of variations in wind speed, site selection, turbine performance), and unsubsidised fuel costs (i.e., indicative of the impact of variations in the marginal baseline levelized cost of energy), as a proxy to the several other changes in input parameters the framework might consider. As such, the DREI model can consider other variables in these sensitivity analyses that can be changed at any of the stages of the assessment process (e.g., country selection, cost of public instrument, levelised cost, capacity factor, rates).

Actual decision-making would require more extensive data collection, country-specific consultations, with further detailed assumptions necessary to enhance the accuracy and reliability of these illustrative results. Examples of additional information required for a full evaluation that might not be captured by these factors include issues of social acceptance, which would impact access to the best wind sites or the location of transmission lines, amongst other factors.

3.2.6 South African Insights

The author contributed to the conceptualization and implementation of this framework drawing on his previous experience supporting the removal of barriers of renewable energy projects in Namibia and Panama. It also drew on the author's vocational education and technical dissemination in South Africa, and the consideration of a broader set of funding sources than grants, that were part of the Equatorial Guinea case study and site visits. The South Africa case pointed to the need of considering both policy and financial derisking instruments, and direct financial incentives – see *Table 5* (below), which applies to, and is indicative of the instruments considered in all other DREI case studies:

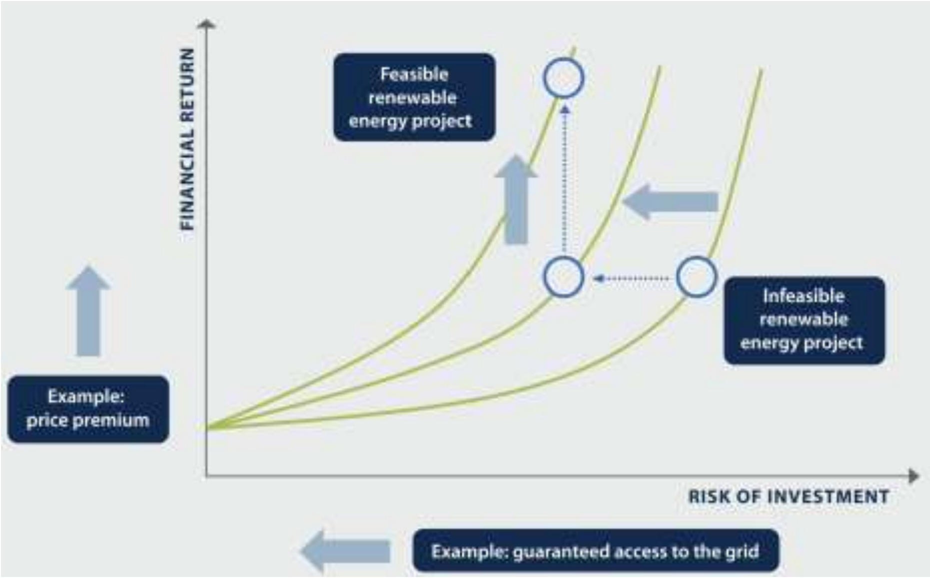
Table 5: DREI Model Instruments



Source: UNDP (2013)

The DREI model application primarily focused on these derisking measures, with *policy derisking instruments* designed to address the underlying barriers to deployment of renewable energy; meanwhile, *financial derisking instruments* designed to shift risks across public and private stakeholders, with *direct financial incentives* only required when there is a positive incremental cost, such that additional instruments are required to make the renewable energy investment feasible – see *Figure 18* (below), for an indicative depiction of how these instruments can address barriers, shift risks and create relevant incentives:

Figure 18: DREI Model Curves



Source: UNDP (2013)

Both the preceding South African case study, and the following Namibian application of the DREI framework, drew on the author's desk and field research. With model applications potentially covering a large range of risks and barriers, *Table 6* (below) provided an illustration of DREI policy and financial derisking instruments, and direct financial incentives that were specifically considered in South Africa, which in the medium to long term required capacity building both on technical (grid code management for the local workforce) and financial barriers (guarantee business development for local banks). The impact of these interventions to address the underlying barriers evolves over time, as shown in *Table 6*, and in both the South African and Namibian case studies:

Table 6: DREI Model Derisking Measures

	SHORT-TERM		MEDIUM-TERM		LONG-TERM
Policy Derisking	Updated grid code for renewable energy	→	Building skills and expertise in grid management	→	Strengthening physical grid infrastructure
Financial Derisking	Providing direct public loans to project developers	→	Providing guarantees for commercial loans (engaging local financial sector)	→	Ideally standalone commercial loans. (Renewable energy is derisked)
Direct Financial Incentives	Adopting tax-based incentives	→	Phase out of fossil fuel subsidies	→	Ideally no renewable energy incentives. (Renewable energy is derisked and competitive)

Source: UNDP (2013)

3.3 Namibia Concentrated Solar Power

3.3.1 Namibian Overview

Namibia was a sparsely populated country with a land area of 824,269 km^2 and a population of just 1.8 million when the author supported the introduction of Concentrated Solar Power (CSP) into the country as a UNDP-GEF adviser in 2008.

At the time, Namibia was a lower-middle-income nation, with a GDP per capita is around USD 1,800 at the time, total electricity consumption was 3,719 GWh, with roughly 50% of this imported from South Africa, whose grid was 90% coal-powered, including coal from Zimbabwe's Hwange power station; its domestic generation capacity was 393 MW, of which 36.6% came from fossil fuels (Nampower, 2008).

According to its White Paper on Energy Policy (Ministry of Mines and Energy, 1998), Namibia's electricity demand was projected to grow by 3% annually over the next 30 years, driven by the Namibian government focus on energy security through the promotion of a diversified energy mix to reduce dependency on any single energy source.

With this in mind, several Namibian stakeholders including the author from both the private and public sectors, with support from various bilateral partners, particularly Germany, engaged in early discussions and initiatives aimed at promoting the development of the CSP technology– see below from the GEF (2009) *CSP Technology Transfer Namibia Project Concept*:

- *Renewables Academy AG* (RENAC), through the Transfer Renewable Energy & Efficiency (TREE) project, which is financially supported by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, organized CSP seminars in five countries, including Namibia, during March and April 2009. Namibia's CSP Seminar, held from March 23-25 was attended by the author, and coordinated by the Renewable Energy and Energy Efficiency Institute (REEEI), bringing together participants from both industry and academia.

- *Rössing Uranium Limited*, a Namibian subsidiary of Rio Tinto, started the exploration of the use of CSP technology for generating process heat. Rössing had established a research cooperation agreement with the Polytechnic of Namibia (PoN) and expressed interest in collaborating on this project.

- *Renewable Energy and Energy Efficiency Institute* (REEEI), through its parent organization, the Polytechnic of Namibia (PoN), had established cooperation agreements with FH Aachen, which hosts the Solar Institute Jülich (SIJ), as well as with RENAC; additionally, research collaboration agreements with the Fraunhofer Institute ISE and Lahmeyer International were being finalized.

- *SUNTEC Namibia (Pty) Ltd*, a local subsidiary of a German company, confirmed its interest in developing a solar thermal power plant with a 5 MW capacity, which would include the plant's installation and commissioning. The proposed project would involve the installation of 32 solar collector assemblies (SCAs) using efficient parabolic trough collectors to capture solar energy (A 6 MVA steam turbine would generate electricity from the solar heat collected).

- *United Nations Development Programme* (UNDP) was the leading international development partner addressing climate change issues in Namibia, actively supporting the Namibian government (Ministry of Mines and Energy).

The author was the UNDP-GEF counterpart to the MME and REEEI based in Namibia, with direct guidance and advisory support from the acting UNDP-GEF regional technical adviser based at UNDP headquarters in New York (USA) – a role that the author would perform for other countries across Sub-Saharan Africa, Latin America and the Caribbean.

These UNDP-supported initiatives contributed to the improvement of energy access, advancement of energy efficiency and development of renewable energy in line with the country agenda. In Namibia, they were designed to address barriers to renewable energy adoption and promoting energy efficiency through GEF-funded projects like the Barrier Removal to Namibia Renewable Energy Programme (NAMREP) and the Namibia Energy Efficiency Programme (NEEP), all implemented by the REEEI.

UNDP had already assisted the Namibian government in the creation of policies to encourage renewable energy, including the Off-Grid Energisation Master Plan (OGEMP) and the Solar Water Heater Cabinet Directive, which mandated the use of solar water heaters in government institutions. The author was directly involved in the introduction and conceptualization of CSP technology in Namibia.

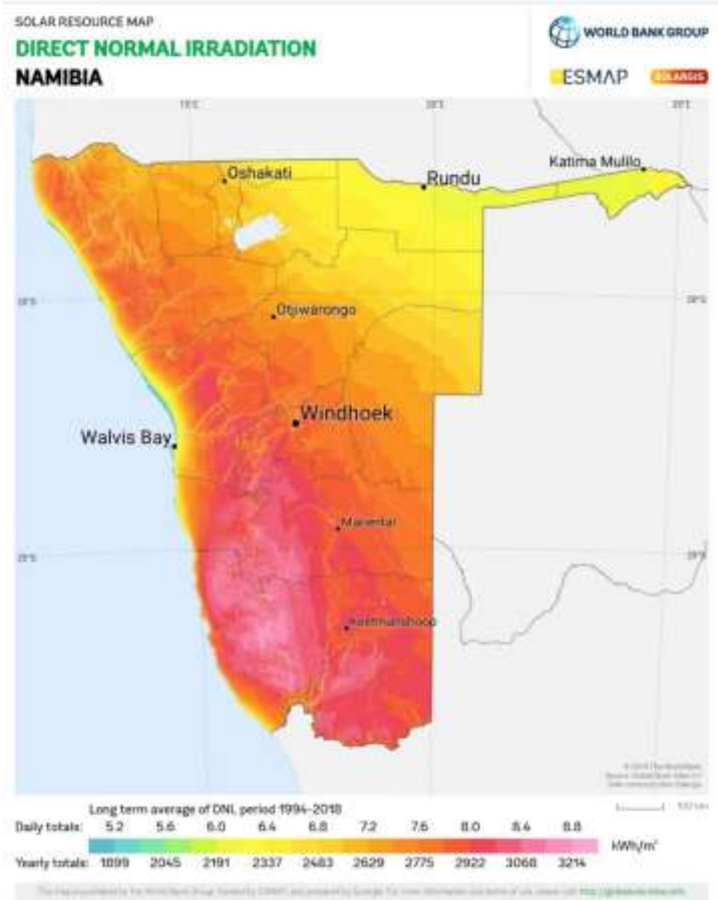
3.3.2 Namibia Risk Environment

The Concentrated Solar Power project was conceptualized and developed with a plant that would incorporate an indirect thermal energy storage system in mind. If backup power from auxiliary gas was required for low or non-solar hours, it would have to be financed separately by Global Environment Facility. The solar power plant would be connected to the grid, to be the first of its kind in the region at the time, utilizing cutting-edge, environmentally friendly technology for power generation.

With this technology transfer mindset, the author developed the concept note of the Namibia CSP project (GEF, 2009). The project was originally conceived to increase the share of renewable energy in the Namibian power generation mix by developing the framework conditions for the successful deployment of the CSP technology for on-grid power generation. In undertaking so the project sought to establish a Namibian CSP industry through technology partnership agreements between foreign and local partners, a policy framework that would be supportive of the required investment, a business environment conducive to financial incentives for projects, and a pre-commercial CSP demonstration plant (originally 5 MW of generation capacity) that would improve confidence in the novel technology for subsequent replication nationally and potentially regionally.

Given the anticipated growth in demand and the government's policy of energy diversification, it was evident that Namibia's electricity generation capacity needed expansion, with a particular focus on developing renewable sources, especially solar energy; Namibia benefitted from one of the world's best solar conditions, receiving an average direct insulation of 2,200 kWh/m^2/year with minimal cloud cover (GEF, 2009) – see *Figure 19* (below):

Figure 19: Namibian Solar Map



Source: World Bank (2019) Namibia Solar Resource Map: Direct Normal Irradiation

Recognizing this potential with one of the best solar resource in the world with DNI ranging up to 3214 kWh per square meter annually (3,214 kWh/m2a), the government actively promoted solar energy, primarily for off-grid applications; yet, Namibia was well-positioned to develop grid-connected solar power on a larger scale, due to its vast land areas ideal for such projects. Grid-fed solar energy would help the country reduce its reliance on carbon-intensive electricity and mitigate climate change mitigation.

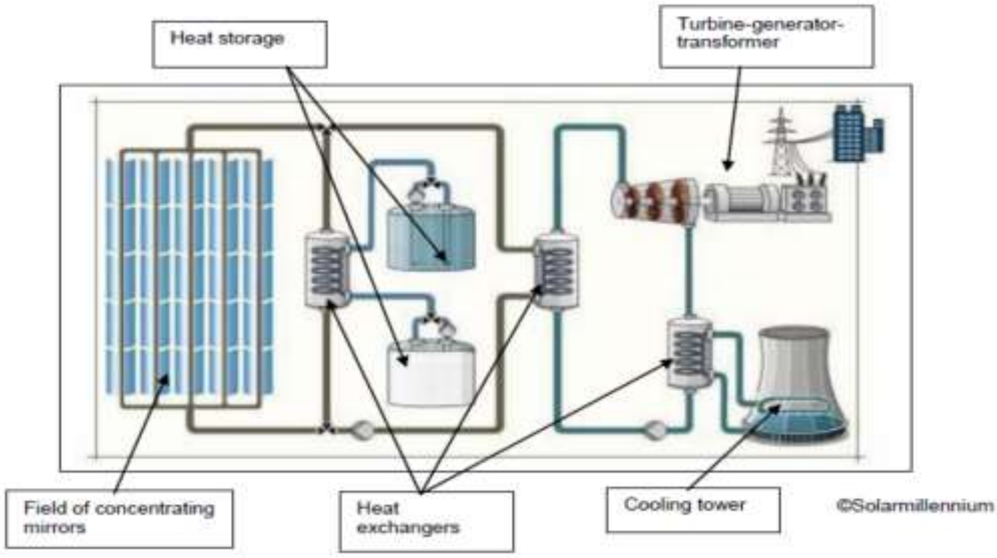
Additionally, Namibia was progressively adopting cost-reflective tariffs for grid-connected energy generation, enhancing the financial viability and investment potential of renewable energy projects. Despite Namibia's climatic conditions for deploying CSP technology, several barriers detailed below were hindering its development, driving a range of often interrelated power market, resource, technology and financial sector risks (*Source*: GEF, 2009):

- *Inadequate financial and regulatory frameworks*: Investors had been reluctant to fund large-scale renewable energy projects in developing nations like Namibia due to the lack of supportive financial and regulatory mechanisms. For clean energy projects to be financially viable, independent power producers needed to sell electricity at fair prices through regulated tariffs or power purchase agreements. Unfortunately, many such countries lacked such tariffs, had poorly structured power purchase agreements, and did not permit excess power transfer through national grids. Additionally, regulatory gaps prevented clean energy projects from benefiting from carbon finance and other schemes. The Ministry of Mines and Energy (MME), the Electricity Control Board (ECB) and the Renewable Energy and Energy Efficiency Institute (REEEI) were responsible to address these issues.

- *Limited technical and financial capacities*: Although local investors, such as mining companies and development banks, were interested in CSP technology, they lacked the necessary technical knowledge and financial resources to develop and adopt it. The lack of investment and financing capacity, a common issue in Sub-Saharan Africa, hampered the ability of project developers to secure adequate funding. Local financiers and developers, unfamiliar with CSP technology, also struggle to design appropriate financing packages and risk management instruments.

- *Lack of access to appropriate technologies*: The development of clean energy projects in Sub-Saharan Africa required the use of modern, though not necessarily cutting-edge, technologies that were often not readily available. Technology transfer involved activities like research and development, training, information sharing, and physical infrastructure transfer. Concentrating solar power was a commercially viable solar technology in a few countries from the Organization for Economic Co-Operation and Development (e.g., USA, Spain, Germany, Israel) countries (with prospects outside OECD countries, including Egypt, Morocco and South Africa), harnessing direct sunlight and mirrors to generate high-temperature steam, driving conventional steam turbines, with or without energy storage –*Figure 20* (below):

Figure 20: CSP Plant Schematic Diagram



Source: GEF (2009) CSP TT Namibia Project Information Form

A typical CSP plant consisted of a solar field, a power block, optional thermal storage, a cooling tower, and other elements common to any thermal power plant, except for the heat source. The main CSP technologies for large-scale applications included parabolic troughs, parabolic dishes with Stirling engines, central receivers, and Linear Fresnel systems. CSP technology was still relatively unknown in the region, at the time dominated by a few companies, such as Acciona (where the author also worked during the COVID-19 pandemic) and Abengoa (Spain); Solar Millennium, Flagsol, FlabegHold GmbH, Schott AG (Germany); Solel (Israel); Archimede Solar Energy (Italy); FPL Energy, SkyFuel, Bright Source Energy, eSolar, and Solar Reserve (USA). This project aimed to introduce CSP technology to Namibia, and thus would encounter a riskier environment than in the above OECD countries.

- *Inadequate local grid codes and standards and limited policy support for technology transfer*: Namibia's grid codes and guidelines were not well-suited for integrating renewable energy technologies. There was a general lack of awareness among policymakers about the potential role of renewable energy technologies in the country's energy mix. This hindered the adoption of policies and regulations that could facilitate the wider diffusion and commercialisation of these technologies.

3.3.3 Namibia Public Instruments

Despite the above barriers, country and regional developments led to an increase of interest by Namibian stakeholders keen to take the necessary steps toward developing and implementing CSP technology policies tailored to local needs. The focus of the derisking interventions associated to the GEF-funded, UNDP-supported *Concentrating Solar Power Technology Transfer for Electricity Generation in Namibia* project were primarily of a policy nature.

They were geared towards enabling technology transfer and pilot project demonstration with funding available through the Global Environment Facility (GEF, 2009). The technology transfer approach recognized Namibia's need for additional power generation capacity, while promoting the adoption of new CSP technologies suited to local conditions. Through adaptive learning from a pre-commercial plant, some of the identified barriers were expected to be addressed, with focus on the initial six months of project implementation on steps to establish a framework conducive to the successful deployment of the CSP project.

These measures would include creating the conditions to encourage private sector participation, laying the groundwork for long-term, self-sustaining CSP market development in Namibia.

Thus, the initial stages of the project focused on:

- Formulating market, regulatory, and institutional policies and partnerships to support CSP development;
- Developing an appropriate policy framework;
- Creating financial incentives and support mechanisms for investment and technology transfer;
- Mobilising stakeholder dialogue; developing regulatory frameworks, including international cooperation agreements for technology transfer;
- Conducting technical and economic assessments for incorporating CSP projects into Namibia's power generation expansion plans – see *Table 7* (below).

Table 7: Namibia CSP Project Barrier Measures

<table>
<tr><th>Barrier Type</th><th>Barrier Measures</th></tr>
<tr><td colspan="2">POLITICAL</td></tr>
<tr><td>Inadequate local grid codes and standards and limited policy support for technology transfer:
➢ Lack of awareness by policymakers of the potential of RE
➢ Inhibited adoption of policies and regulations to increase CSP diffusion</td><td><u>Market Policy Framework for CSP Technology</u>
The project barrier removal activities were designed to ensure that a policy framework was created to facilitate and guide the deployment of CSP technology, including the development of technical interconnection standards and guidelines for power purchase agreements, to achieve two key results:
▪ Approval of policies that support the application of CSP technology.
▪ Establishment of a robust CSP market in Namibia.</td></tr>
<tr><td colspan="2">COMMERCIAL</td></tr>
<tr><td>Inadequate financial and regulatory frameworks:
➢ Lack of market access and finance viability for independent power producers through tariffs and power purchase agreements
➢ Lack of schemes and incentives to attract innovative finance (e.g., carbon finance)</td><td><u>Business Model and Financing Framework for CSP Projects</u>
The project barrier removal activities included conducting a detailed analysis of CSP technologies and developing a comprehensive business case and financial model to establish the foundation for setting up a pre-commercial CSP plant and defining its technical, financial, and economic parameters, with the following expected outcomes.
▪ Financial institutions and banks offering loans for CSP projects.
▪ Increase in the number of CSP installations within the country.</td></tr>
<tr><td colspan="2">INSTITUTIONAL</td></tr>
<tr><td>Limited technical and financial capacities:
➢ Lack of technical and financial resources and expertise to develop CSP
➢ Lack of investing and financing capacity for capital-intensive renewable energy projects</td><td><u>CSP Pre-commercial Demonstration Plant</u>
The project was designed to support demonstrating the operation of a 5 MW CSP facility, including authorizations, bankable solar resource assessment, basic design and feasibility study of the potential of solar collector technologies (parabolic trough, central tower, and linear Fresnel), with both storage and non-storage options, tendering the identified technology and agreeing on conditions to achieve the following (below):
▪ Increased confidence among the government and public in the technical and economic feasibility of CSP.
▪ Multiple replications of the CSP plant</td></tr>
<tr><td colspan="2">TECHNOLOGICAL</td></tr>
<tr><td>Lack of access to appropriate technologies
➢ Limited research and development on CSP
➢ Lack of CSP training, information and technology dissemination
CSP technology was concentrated among a few players in Germany, Israel, Italy, Spain, the U.S., and other OECD countries with advanced applied research</td><td><u>Formation of CSP Technology Partnerships</u>
The project was designed to conduct a scoping and due diligence analysis of global CSP players (leveraging networks developed through the TREE project CSP Seminar) and solidify key partnerships through memoranda of understanding to facilitate technology transfer. Efforts were made to build interest among local industries, such as the Namibia Chamber of Commerce and Industry, ensuring they were involved from the start, as follows:
▪ Establishing technology partnerships between foreign CSP providers and Namibian stakeholders, including the private sector, academia, and government.
▪ Increasing knowledge of CSP applications relevant to Namibia.</td></tr>
</table>

Source: Author's contribution to GEF (2009) CSP TT Namibia Project Information Form

The above barriers to the Namibia CSP project success were identified as underlying the following initial risks assessed, and mitigation measures considered at the conceptualization of the project – see *Table 8* (below)

Table 8: Namibia CSP Project Risk Mitigation

Risk Type	Risk Mitigation Measures
HIGH	
Power Market Risk: *New electricity generation capacity in Namibia, and reallocation of priorities within national power generation programs, could need increased fiscal transfers or higher consumer tariffs compared to fossil fuel options.*	Future tariffs for fossil fuel-based electricity would rise considerably, which would in turn naturally encourage the adoption of renewable energy technologies with addition of new electricity generation capacity. This would significantly impact future electricity prices in Namibia.
MEDIUM	
Permits Risk: *Lack of collaboration among key government ministries and institutions could hinder the development of policy and regulatory measures to promote CSP technology transfer and adoption.*	This challenge would be addressed by establishing a comprehensive stakeholder consultation and engagement plan that is inclusive and executed with care.
Financial Sector Risk: *Inability to establish suitable arrangements and financial incentives to attract both domestic and international private investments, as well as secure financing and demonstrate the feasibility of the 5 MW demonstration plant.*	This risk would be mitigated by involving the private sector in identifying barriers, risks, and constraints, the development of measures and tools to encourage their participation. Ensuring commercial viability will be a key factor in securing private sector engagement.
Resource/Technology Risk: *The inability to gain support for establishing technology partnerships between technology owners and relevant local entities critical in the CSP supply chain.*	This risk would be partially alleviated by leveraging the knowledge and connections of UNDP and its specialized partner agencies. Additionally, the project will aim to engage all key stakeholders from the beginning.
Macroeconomic/Currency Risk: *Inflationary pressures, along with the global economic downturn, had significantly affected the growth of Namibia's economy in the past, and thus could impact the volatility of the Namibian Dollar (pegged to the South African Rand) and the interest rate outlook.*	The medium-term outlook appeared positive, yet inflation and economic downturns would lower consumption and demand, and reduce the motivation to invest in new power. Technical and economic studies would need to include strategies to minimize the impact of inflation and economic crises on the deployment of CSP technologies.

Source: Author's contribution to GEF (2009) CSP TT Namibia Project Information Form

The Namibia CSP project development entailed several barrier removal and derisking activities underscores above ahead of the adoption of a new technology in a new EMDE context that would require the following deployment activities: (a) *Project Construction*, e.g., groundbreaking and mobilization, reassessment, detailed engineering, and earthworks, equipment delivery, civil construction, assembly of primary equipment, and pre-commissioning activities; (b) *Warranty Period*, e.g., the conduct of trial runs and fine-tuning of the CSP plant; (c) *Plant Operation*, e.g., operation and maintenance (O&M), staffing, mirror damage, storage options, reflectance, heat loss, monitoring and documentation of operational metrics like power generation, water usage, and climate data.

The above range of public instruments, barrier removal activities and policy/financial derisking measures were required to facilitate CSP investment in Namibia with the anticipation that any risk premiums would decrease while insights were gained regarding risk and environmental impact mitigation. Ultimately, the project aimed at fostering the development of local entrepreneurs and technologists who could effectively integrate various technologies and experiences for large-scale power generation and process heat replication.

In-depth analysis of the plant's installation and operational aspects would also equip local experts with the knowledge and skills needed to design, operate, and maintain CSP plants in the future, requiring minimal foreign assistance except at critical junctures. Furthermore, the installation and operation of the plant would create benefits, including both direct jobs (in manufacturing, contracting, and construction) and indirect jobs (in services).

The implementation of CSP technology in Namibia was set to yield global environmental benefits as well as developmental advantages for the country. Specifically, the shift from fossil fuel-generated electricity to a 5 MW CSP plant was expected to prevent approximately 10,700 tons of CO_2 emissions per year, based on a 25% load factor.

3.3.4 Namibia Levelised Costs

The Namibia CSP technology transfer project was designed and developed to achieve direct CO_2 emission reductions of 10,700 tons per year. Most climate change mitigation efforts would stem from the subsequent deployment and operation of a 5 MW CSP demonstration plant designed to replace approximately 10 GWh per year of fossil fuel-based electricity.

Over a 15-year plant lifespan, total direct CO_2 emission reductions will amount to around 160,500 tons, the estimated cost of emissions reduction, based on the US$ 1.7 million grant contribution from the Global Environment Facility, was approximately US$ 16.1 per ton of CO_2. This cost could improve if indirect CO_2 reductions from future replications of the CSP technology, implemented during or after the project, are taken into account.

When the author was involved in the conceptualization of the project, CSP technology was particularly attractive to utilities due to its lower costs and scalability compared to photovoltaic technologies. The Namibian electricity utility (NamPower) involvement in the project was to help minimize uncertainties related to power purchase agreements and the adequacy of transmission infrastructure.

The planned plant location included a 24 MVA turbine generator that would connect to an existing substation with appropriate voltage levels near the solar site, in order to reduce costs. At the time, the parabolic trough CSP system was considered as it required less land per MW of installed capacity than other CSP technologies (e.g., tower or dish-engine). In addition, its shorter implementation lead time—supported by the developer (SUNTEC) eagerness to start construction—was expected to reduce costs, resulting in a lower LCOE.

The envisioned grant funding from the GEF sought to remove barriers and promote the expansion of renewable electricity generation through CSP technology led by Namibian developers with backing from national and international financial institutions. The objective was to enable technology transfer through a learning-by-doing approach, to build confidence among local stakeholders, and enable future CSP deployments with increased Namibian involvement, which would improving the cost-effectiveness of CSP technology.

Namibia faced energy security challenges due to the Southern African Power Pool power shortages, including South Africa's struggle to meet its own energy needs and reduced ability to export power. CSP was to provide Namibia one option to become energy-independent, given the SAPP risks, prompting the country to enhance its energy generation capacity and diversify its energy sources through solar power. CSP’s relatively high cost required application in regions with optimal solar radiation and investment frameworks. Namibia solar resources average 2,200 kWh/m^2/year with minimal cloud cover, so CSP was set to become cost competitive, i.e., US$ 0.10-0.16 per kWh by 2025-2030 (IRENA, 2014-5).

3.3.5 Namibia Evaluation

The Namibian Concentrated Solar Power Technology Transfer project was carried by UNDP as the GEF implementing agency, and the Ministry of Mines and Energy as the executing government partner starting effectively in 2014 –see project outcomes summarised in *Table 9* (below):

Table 9: Namibia CSP Project Outcomes

Outcomes	Indicators	Baseline	Target	Assumptions
Project Objective **To increase the share of renewable energies in the Namibian energy mix by CSP technology** **(GEF: USD1,718,000.00)**	▪ Cumulative direct post-project MT CO_2 emission reduction from CSP ▪ % share of CSP in national power generation mix	▪ 0 ▪ 0	▪ 0 ▪ 0	-Economic growth continues -Government support for RE remains
Outcome 1: **Local entrepreneurs are engaged in the manufacturing, supply and installation of CSP systems by year 3** **(GEF: USD 175,490.00)**	▪ No. of government-endorsed CSP partnerships ▪ No. of local firms with CSP design experience ▪ No. of local CSP-related manufacturing, supply and installation companies	▪ 0 ▪ 0 ▪ 0	▪ 5 ▪ 7 ▪ 10	-Time, human, technical and financial resources available in MME and REEEI.
Outcome 2: **Increased investments in CSP technology applications in Namibia** **(GEF: USD460,187.00)**	▪ No. of sites with investment grade solar resource data ▪ No. of investments facilitated by CSP development guidelines ▪ No. of planned and approved CSP projects funded by local institutions	▪ 0 ▪ 0 ▪ 0	▪ 5 ▪ 1 ▪ 2	-Solar data is made available to CSP investors -Stakeholders are available -Government staff committed to CSP
Outcome 3: **Increased installed capacity of CSP plants in Namibia by end of project (EOP)** **(GEF: USD910,735.00)**	▪ No. of planned, approved and financed CSP projects replicating the first CSP ▪ MW of cumulative installed power generation capacity from CSP plants by EOP ▪ Set of regulations promoting the development and operation of CSP plants mainstreamed into local / national guidelines	▪ 0 ▪ 0 ▪ 0	▪ 0 ▪ 0 ▪ 1	-MME and REEEI time to invest in CSP information, to support local authorities -Global capital markets funds for CSP plants - EIAs for CSP sites approved -Ministry of Finance provides sovereign guarantees to facilitate debt

Source: Author's contribution to UNDP (2017)

After inception delays in establishing project management arrangements the ministry delegated the project management to the Namibia Energy Institute at the Namibia University of Science and Technology (formerly, Renewable Energy and Energy Efficiency Institute at the Polytechnic of Namibia leading efforts on technology transfer and local capacity building, and NamPower (national electricity utility) taking the lead on feasibility assessments.

The project outcome indicators (above) varied from its initial design framework, project components and expected outputs, with an original significant focus on, and grant resources (US$1,246,412 specifically for technical assistance and advisory services under Component 4) devoted to the research, development and demonstration of a 5MW Concentrated Solar Power plant (*Table 10*, below):

Table 10: Namibia CSP Project Outputs

Project Components/ Outcomes	Project outputs	GEF budget (USD)
Objective: To increase the share of renewable energies in the Namibia energy mix by *developing the necessary technological framework and conditions for the successful transfer and deployment of CSP technology for on-grid power generation*		
Component 1: Establishment of CSP technology industry. Outcomes: • Technology partnership agreements are finalized foreign technology providers and Namibian partners including private sector, academia and government • Enhanced knowledge of applicable CSP applications in Namibia	1.1 National Technology Transfer Coordinating Body (CTTCB) is operationalised 1.2 Partnership agreements in place with at least two partners: (a)South- South and (b) North-South	50,000
Component 2: Market Policy Framework for CSP technology Outcome 2: • Approved policies supportive of CSP technology • A thriving CSP market in Namibia	2.1 Approved CSP investment guidelines 2.2 Approved CSP technical guidelines for grid quality	125,000
Component 3: Business Model and Financing Framework for CSP projects Outcomes: • Financing institutions/banks providing loans to CSP project • Increased number of CSP installations in the country	3.1 Approved package of financial incentives for CSP projects; 3.2 Tailored financing packages for CSP technology; 3.3 Established and enforced national CSP promotion strategies	125,000
Component 3: CSP Pre- Commercial demonstration plant Outcomes: • Improved confidence of the government and citizenry on the techno-economic viability of CSP • Several replications of the CSP plant	4.1 Detailed techno-economic feasibility reports 4.2 Demo CSP plant (5MW) built 4.3 O&M and performance reports 4.4 Technical performance manuals 4.5 Trained local technicians on the design and operation of CSP plants 4.6 Engineering curricula that incorporate CSP technology design and applications 4.7 Approved monitoring indicators for baseline mid and end-of-project analysis 4.8 Documented and disseminated project results	
Project Management / M&E		171,588
Total		1,718,000

Source: UNDP (2017)

After the author's contribution to the design of the Namibia CSP project, its subsequent implementation required modifications reflective of both the longer lead times required for the research, development, technology transfer and diffusion elements of CSP deployment in a new market. Its introduction and conceptualization faced delays as a result, but the revised results framework also reflected the needed economies of scale to enable its shift to commercialization. As a result, the project needed to increase the generation capacity of the demonstration plant, also due to the trends captured in the *Section 3.3.6* (below).

The initial concept was submitted to the GEF in November 2009, it was included in the GEF Work Program for approval in May 2010 and received GEF full project endorsement in December 2012. Thereafter, there were additional delays before the final project document was finalized with the *Table 9* results (UNDP, 2017).

Additionally, the project's mid-term Review in 2015 noted that the project's indicators were overly ambitious given the typical duration of commercial CSP projects at the time. CSP projects involve concept development, measurements, feasibility studies, financial planning, and moving through design, construction, and commissioning to the production stage, therefore completing such a project in just three years was later deemed unrealistic (UNDP. 2017).

The final project document itself acknowledged that constructing a large CSP plant within that timeframe would have been impossible, and no direct CO2 reductions could have been expected. In short, UNDP argued later on that reaching financial closure between 2014/15 and 2016/17 for was then envisioned to be a 50-150 MW project using novel CSP technology was highly optimistic, as site-specific solar data measurements alone require at least one year, given the time required to finalize full feasibility studies, formalize partnerships, financial planning, and contract negotiations.

As the author's contribution to the original design conceived, the technology transfer and capacity building focus of the project centred around the deployment of a small 5 MW demonstration unit. The assumption was that once regulatory frameworks were strengthened, local finance mobilized, and technical capacity developed, these small CSP units could be replicated commercially. The concept also envisioned local companies, supported by local financiers, leading the development of small-scale renewable energy IPP projects, which would eventually attract global CSP players to build large-scale, commercially viable facilities. It did become clear later on that the diffusion of CSP technology would follow a different trajectory. Unlike photovoltaic power, CSP was less scalable in terms of cost efficiency at the time. However these trends also evolved, which led to the consideration of demonstration plants of a larger generation size.

The global trend became constructing larger CSP facilities (15-100 MW) through national utilities or global CSP players and investors. These larger, often government-supported projects would demonstrate the technical and commercial viability of CSP, in contrast with the impact of a small 5 MW plant.

Once costs decreased and viability is proven, local or regional companies would be more inclined to develop smaller independent power producing CSP projects. However, the successful deployment would ultimately depend on having a policy and regulatory framework in place that is supportive of IPPs, and help remove the barriers identified above. Therefore, policy was key for the feasibility of CSP.

The shift from demonstration to commercialization extended the necessary longer decision-making processes to unlock the needed private sector investment. The lead time to deploy a larger (up to 50 MW) CSP commercial plant was much longer than the 3 years envisaged for a smaller (5 MW) pilot demo. Hence, when the scope of the initial concept shifted, the revised project scope timelines should have shifted accordingly; however, one barrier also likely affecting the decision to invest is the availability of GEF funding for a longer period, vis-à-vis the funder incentive for a larger investment that would achieve bigger global environmental benefits (i.e., greenhouse gas emission reductions).

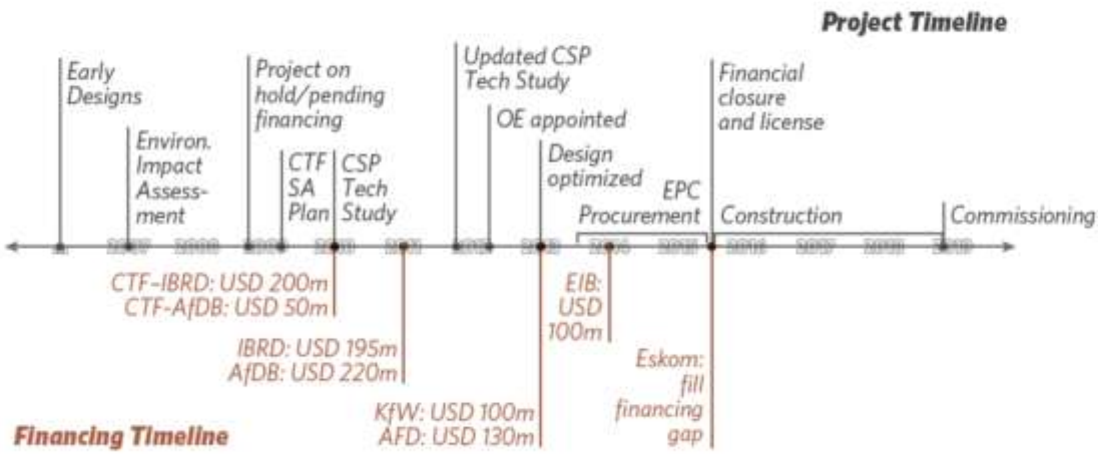
3.3.6 Namibian Insights

This may be the dilemma facing other renewable energy deployments in nascent technologies. They are caught up between the need to give time and space to research, development and innovation, and the demand to fast-track deployment and commercialization. Of note, at the time the author helped conceptualize the Namibia CSP project in 2009, no other such developments existed in the region.

By the time the final project document was endorsed for funding 3-4 years later, South Africa had already started development of a CSP plant with larger financing from the Climate Investment Funds (CIF) than the Global Environment Facility (GEF) could ever provide. The CIF financing package included a series of derisking instruments over time, which supported a comparative longer timeline before final investment decision and financial closure that the GEF support.

In addition, multilateral development banks (MDBs) such as the World Bank (WB), African Development Bank (AfDB) and European Investment Bank (EIB) were the implementing agencies in South Africa, with a stronger comparative advantage than the United Nations Development Programme (UNDP) in leveraging non-grant mechanisms (debt, equity, guarantees), and catalysing private sector investment, backed by public finances –see *Figure 21* (below):

Figure 21: South Africa CSP Plant Timelines



Source: Climate Policy Initiative (2014)

As depicted, the timelines for the South African CSP facility near Upington span over a decade, including at least 10 years of project preparation, in addition to the years required for CSP commissioning. The role of the financier in decision-making was key, as this facility required the involvement of up to 3 MDBs (WB, EIB, AfDB), the availability of larger funding envelopes of double- and triple-digit millions of US Dollars (including finance from the CIFs) versus the single-digit millions of US Dollars for the Namibia GEF-funded, UNDP-supported CSP project.

In addition, other CSP developments were under consideration in the Southern African region beyond the South African 100 MW CSP project implemented by its national utility (Eskom), like a 200 MW CSP plant feasibility study for Botswana.That said, at mid-term stage of project implementation, the Namibian CSP project had achieved results contributing to the derisking of renewable energy investment, and removal of the barriers the project was going to face. Regional market dynamics in neighbouring encouraged national stakeholders to consider measures to further strengthen business and regulatory environment.

These included inputs to the process of developing the Namibian renewable energy policy, which after the project was incepted it would include the target of a 125 MW CSP plant as also part of the 4th National Development Plan. Hence, scale was also influenced by domestic ambitions despite GEF funding constraints.

The project also initiated the establishment of a CSP investment database for use by market players across the public and private sectors. The selection of three CSP sites included the installation of equipment for solar radiation and measurements; and the provision of CSP training, capacity building and multistakeholder networking and awareness-raising. While not measured with the same figures or indicators of the South Africa DREI case study, the Namibian project demonstrated strong elements of investment and savings leverage, combined with signals of end-user affordability and carbon abatement potential.

With the project initial budget (US$1.7m grant from the Global Environment Facility), the project aimed to secure government approval and achieve financial closure for one CSP plant based on a solid business and investment plan. The rapid removal of barriers to set up with Namibia's first CSP plant became a distant objective, given the time lags mentioned earlier, which included discussions regarding the adequate business model (e.g., state-owned, privately-owned, or a public-private partnership). That said, public instruments such as technical assistance for environmental impact assessment, techno-economic and macroeconomic studies were completed, including a full year of solar radiation data collected for the Auas, Kokerboom, and Arandis sites across Namibia.

Despite these and other changes in project outputs, which are typically part of the adaptive management necessary in GEF-funded UNDP-supported projects, outcomes contributed to the market transformation needed for CSP deployment in Namibia. Its planned investment leverage at its design stage is reflected in *Table 11* (below), which included catalysing co-finance from the private sector (incl. national power utility operator NamPower, potential developer SUNTEC Namibia, off-takers national water utility NamWater, and Rössing Uranium Ltd.) and financial institutions (e.g., KfW Bank).

Table 11: Namibia CSP Concept Funding

	Previous Project Preparation Amount (a)[2]	Project (b)	Total c = a + b	Agency Fee
GEF financing		1,718,000	1,718,000	171,800
Co-financing		18,436,000	18,436,000	
Total		20,154,000	20,154,000	171,800

Sources of Co-financing	Type of Co-financing	Amount
Project Government Contribution	Grant	746,000
Project Government Contribution	In-kind	450,000
GEF Agency(ies)	Grant	
Bilateral Aid Agency(ies)	Soft loan & Grant- KfW bank, DANIDA	450,000
Multilateral Agency(ies)	Unknown at this stage - EU (EU AID/128320/C/ACT/Multi- ENRTP Priority 5/Lot 11)	770,000
Private Sector	**In-kind**– Polytechnic of Namibia, Chamber of Mines, NamPower, Renewables Academy AG (Germany),	520,000
Private Sector	**Cash** – Rössing Uranium Limited, NamWater, Electricity Control Board (ECB)	500,000
Private Sector	**Cash/In-kind** (e.g. plant, installation, commissioning) – SUNTEC Namibia (Pty) Ltd	15,000,000
Total co-financing		18,436,000

Source: Author's contribution to GEF (2009) CSP TT Namibia Project Information Form

The project supported the development of national policy frameworks (including the renewable energy policy, IPP framework, integrated resource planning, and updated national energy policy), with the government endorsement process underway. After GEF grant approval, full feasibility study for a 100-150 MW CSP plant was considered (instead of the original 5 MW at the concept stage, or subsequent 50 MW target at the full grant approval stage), and progress on site selection (Arandis or Kokerboom), solar mapping, and the formulation of the techno-economic and environmental impact assessments neared completion.

In the end, a draft concept note for a 135 MW base-load facility with thermal energy storage at Arandis (south of Namibia) was developed, shifting the project goal from supporting technology transfer, with the demonstration of a small pilot CSP facility involving a local-based independent power producer, to facilitating investment in Namibia's first large-scale CSP plant, spearheaded by NamPower.

As a result, the investment leverage shifted as reflected in *Table 12* (below), and the drop in investment leverage ratio from over 10:1 at concept stage to 3:1 at project stage reflected the shift from an internationally private-led barrier removal approach for the deployment of concentrated solar power generation to a locally public-led policy derisking process, driven by the Ministry of Mines and Energy and the state utility.

Table 12: Namibia CSP Project Funding

Co-financing (type/source)	UNDP own financing ('000 USD)		Government (MME, NAMPower and NEI) ('000 USD)		Private sector ('000 USD)		Total ('000 USD)	
	Planned	Actual	Planned	Actual	Planned	Actual	Planned	Actual
Grants			340,000	5,501,000	450,000		790,000	5,501,000
Loans/ Concessions								
In-kind support			80,000	80,000			80,000	80,000
Other								
Totals			420,000	5,581,000	450,000		870,000	5,581,000

	Cash		In-kind		Total	
	Committed	Disbursed	Committed	Disbursed	Committed	Disbursed
DBSA	350,000				350,000	0
Clinton Climate Initiative	100,000				100,000	0
MME	340,000	340,000			340,000	340,000
MME-National Energy Fund *)		836,000				836,000
NamPower **)		3,565,000			0	3,565,000
NamPower ***)		760,000				760,000
NEI			80,000	80,000	80,000	80,000
Total	790,000	5,501,000	80,000	80,000	870,000	5,581,000

Source: UNDP (2017)

The project actively engaged with the domestic private sector to enhance its capacity for contributing local content within the CSP supply chain, shaped CSP policy to create a favorable environment for private investment, and raised awareness through training workshops and networking engagements.

NamPower took a leading role, supported by the Ministery of Mines and Energy, and backstopped by the Namibian Energy Institute at the Namibia University for Science and Technology (formerly Renewable Energy and Energy Efficiency Institute at the Polytechnic of Namibia). The latter lead to the integration of CSP-related content into technical manuals and curricula, and the provision of capacity development for over 200 private potential entrepreneurs, including developers, engineers, installers, manufacturers, and financiers, who gained exposure to South-South and North-South technology transfer (UNDP, 2017).

Despite this seemingly negative evaluation of both savings and investment leverage in quantitative terms, the GEF-funded and UNDP-supported Namibia CSP project laid important groundwork to support its future deployment in qualitative terms. According to UNDP (2017), it grew interest in utility-scale renewable energy generation in Namibia, with increasing focus on Concentrated Solar Power, as shown by the drafting of the National Integrated Resource Plan and the National Renewable Energy Policy.

CSP was identified as a key option in these plans, with the project initially aiming to facilitate a 5 MW pre-commercial plant, which then expanded into supporting the development of a 135 MW commercial-scale CSP facility of an estimated US$1 billion investment (the National Integrated Resource Plan also mentioned 250 MW installed capacity by 2030-35). The application of the DREI derisking approach showed that success or failure might not always be quantifiable.

The research also shows that quantitative indicators, when contextualized might uncover qualitative impacts that public instruments can have. In the author's educational and professional experience, the latter tend to be more relevant, like Namibia showed. At inception, a smaller plant was seen as less risky, yet the larger size become reflective of increased risk appetite informed by derisking. In terms of savings leverage ratio and end-user affordability, the research showed that the Namibia CSP project planned to utilize one of two proven technologies (i.e., either the central receiver tower, or parabolic trough).

As IRENA (2015) analysis confirmed then, CSP costs were decreasing worldwide, with capital costs for parabolic trough plants decreasing by 20% to 45% and solar towers by up to 28% in 2025 compared to 2010-11 levels. The resulting decreasing cost of CSP solar towers, which could generate electricity at a cost of USD 0.11 to USD 0.15/kWh on average by 2025, must be assessed vis-à-vis the cost of the public instruments. While the Namibian CSP project was not yet operational towards the end of the author's research period, sources confirmed the validity of this potential cost reduction trajectory. According to SolarPACES (2021), NamPower remained flexible on the core CSP technology of choice, with the only stipulation being that it must be dry-cooled.

The first CSP plant was expected to be completed by 2025, with an estimated cost ranging between US$600 million and US$1 billion with "build, own, operate, transfer" model, transferring ownership to NamPower after 25 years. It would be procured through a public-private partnership under Namibia's new Public Private Partnership Act targeting a tariff below US$8 cents/kWh depending on the plant's final size, storage capacity, and dispatch times, with no subsidies planned. Therefore, applying the DREI model evaluation, the Namibia CSP project is expected to attain savings leverage and end-user affordability, in comparison with initial estimates at its design stage. The CSP project will intend to supply power during peak demand, complementing daytime solar PV and providing energy during Namibia's hydropower dry season, from April to October (ibid.). Thus, it would help create a more balanced Namibian renewable energy grid, while addressing the energy security concerns the country still faces over its dependency on imported largely coal-fired power from neighbouring Bostwana and South Africa.

This aspect also remains relevant from a carbon abatement perspective (see *Table 13*, below), since CSP power generation would also contribute to Namibia's to climate change mitigation goals, and global commitments under the Paris Climate Agreement:

Table 13: Namibia CSP Carbon Abatement

Indicator	Baseline	Target
1. Cumulative direct post-project CO2 emission reduction resulting from the investment in CSP by end-of-project (EoP)	0	5.83 $MtCO_2$
2. % share of CSP in the power generation mix of Namibia by EoP	0	10%

Source: UNDP (2017)

Once operational, the CSP plant would increase the proportion of renewable energy in Namibia's energy mix. The inception of the establishment of the technological framework and conditions necessary for the successful transfer and deployment of CSP technology for grid-connected power generation can be attributed to the GEF grant.

As a policy derisking public instrument, the technical assistance supported by UNDP might not be fully credited with the increased percentage share of CSP in Namibia's power generation mix, nor the final investment decision nor cumulative direct post-project CO2 emission reductions.

From the DREI model perspective, policy derisking instruments were effective in addressing barriers to deployment of CSP technology in Namibia. Based on the author’s above field and desk research, these studies, technical assistance and capacity development interventions helped tackle their root causes. Initially, the Namibian government showed limited interest in other utility-scale renewable energy technologies, and the state utility adopted a wait-and-see approach. However, the grant-funded project played a key role in bringing Concentrated Solar Power to the forefront of the government's energy planning strategy.

This led to the development of a renewable energy and independent power producer-friendlier investment policy and regulatory environment that included explicit targets for CSP deployment. The Ministry of Mines and Energy indeed prioritized CSP as one of the top three options for ensuring energy security with its commitment alongside NamPower to facilitate the development of a 135 MW CSP plant. Namibia is also enforcing policies to ensure cost-reflective electricity pricing and tariffs, and introduced an environmental tax on carbon-emitting fuels, which would help make CSP more competitive.

For instance, the levelised cost of energy for the prospective Arandis plant in 2025 was estimated to be around US$ 0.15-0.17/kWh (UNDP, 2017), if not less based on other desk research. While this would be slightly higher than the US$ 0.11-0.165/kWh that was projected to be the cost of imported energy during peak times in 2017-2018 (ibid.), CSP would offer energy security benefits and an improved macroeconomic environment reflected in balance of payments from lesser dependent on imported fossil fuels. In 2016-2017, around NAD 2.6-3 billion was spent on energy imports, and thus the 135 MW CSP facility could save approximately NAD 0.9-1.2 billion by reducing reliance on imported electricity (UNDP, 2017).

Despite the high investment cost, the project remains highly likely to move forward as the government views have shifted on what would be strategically important for securing a sustainable power supply, fostering industrial development, and enhancing energy security. As noted above, the commissioning of Namibia's first CSP plant was not anticipated to occur within the 3-year GEF-funded UNDP-supported project timeline (initially planned from 2012 to 2015).

Notwithstanding, while the actual commissioning of the CSP plant would not take place during this technical assistance period, the preparatory steps for its future deployment can be directly linked to this support. At the time of its design in 2009, no other CSP deployment was in place nor operational in the Sub-Saharan African region. Yet, with different investment contexts, policy and financial derisking instruments at play, other projects came on stream since then, such as Morocco's MASEN model and South Africa's REIPPP (SolarPACES, 2021).

NamPower's derisking included selecting sites with strong solar potential, gathering three years' worth of DNI measurements and contributing to the reduction of development costs (ibid.). NamPower plans to focus on procuring the successful bidder and supporting the developer in securing the necessary approvals and permits, while overseeing compliance with performance and contractual obligations.

Feasibility assessments will consider electricity demand, technology trends, risks, and contingent liabilities to define project objectives and risk allocation. As the CSP plant seeks to provide dispatchable energy, NamPower plans to require guaranteed performance from the developer, with compensation provided for unavailability or capacity shortfalls (ibid.).

The application of the DREI model to a new technology (CSP vis-à-vis wind) in Sub-Saharan Africa, and the comparison of the same technology in two neighbouring countries (Namibia and South Africa), shows the need to consider variations in both DREI model and NWHRM approaches in order to assess the barriers to deployment of renewable energy. The next chapter explores the DREI application in the Latin American region.

4 Evaluation of Barriers in Latin American Countries Applying the Derisking Renewable Energy Investment Model

4.1 Latin American Context

The DREI original framework was also applied to Latin America. The 2013 report included one case study: Panama. This is covered next in the PhD thesis, where the author also engaged different stakeholders on several occasions and lived in the country during four years in a high-level, senior technical advisory capacity.

The Panama case draws on the author's professional experience in assessing and addressing the barriers to deployment of renewable energy across Mesoamerica, including Mexico and the Central America sub-region, and South America, including Brazil, Andean and Southern Cone sub-regions.

While the focus is on the Panamanian wind power landscape, this section also draws on the author's desk and field research, for the mobilization of technical assistance, advisory services and analytics, investment project financing and other derisking instruments (development policy loans, credits and guarantees, amongst other innovative financing mechanisms, e.g., carbon finance) – see *Table 14* (below) for a non-exhaustive list of renewable energy projects the author considered, their related derisking instruments by grant type and fund source:

Table 14: Latin American Derisking Instruments

<table>
<tr><th rowspan="2">Type</th><th rowspan="2" colspan="2">Funding Source</th><th colspan="5">Renewable Energy Technology</th></tr>
<tr><th>Small Hydro</th><th>Large Hydro</th><th>Solar CSP</th><th>Solar PV</th><th>Wind</th></tr>
<tr><td rowspan="2">Grant</td><td>Multi-lateral</td><td>GEF</td><td></td><td>-Paraguay Itaipu (WB)</td><td></td><td></td><td>-Mexico (UNDP)</td></tr>
<tr><td>Other Grants</td><td>Paraguay</td><td colspan="5">-Paraguay Itaipu Reimbursable Advisory Service (WB)</td></tr>
<tr><td rowspan="7">Non-Grant</td><td rowspan="2">Loans</td><td>Investment Project Financing</td><td colspan="5">-Mexico Sustainable Energy Technology Development (WB)</td></tr>
<tr><td>Development Policy Loan</td><td colspan="5">-Colombia Green Growth (WB)</td></tr>
<tr><td rowspan="2">Equity</td><td>Acciona</td><td></td><td></td><td></td><td>-Chile El Romero</td><td>-Mexico Oaxaca</td></tr>
<tr><td>Multilateral Development Banks</td><td>-Honduras RE Fund (IADB)</td><td>-Honduras El Cajón (IADB)</td><td></td><td></td><td></td></tr>
<tr><td>Guaran-tees</td><td>World Bank Group</td><td colspan="5">-Argentina FODER Renewable Fund Guarantee</td></tr>
<tr><td>Carbon Funds</td><td>Carbon Pricing</td><td colspan="5">-Shadow Carbon Price Use (CPLC Partnership)
-Chile, Costa Rica and Mexico (REDD+ Carbon Instruments)</td></tr>
<tr><td>Other</td><td>Corporate</td><td colspan="5">-Brazil, Mexico and Panama Philanthropy (Acciona.org)</td></tr>
</table>

Source: Author's desk, field research compilation and contribution

In four years (2011-2015) from his base in Panama City, the author undertook field missions and site visits to all countries of the Latin America continental shelf (with the exception of Belize, Guatemala and Uruguay that were otherwise covered by desk research and project advisory engagements, not listed in *Table 14*). The engagements included provision of advice, dissemination of knowledge and mobilization of finance to address barriers of sustainable infrastructure deployment, not only of renewable energy, but also resilient infrastructure, sustainable transport, pollution management and environmental health projects.

This exposure was critical for the author's later oversight of both UNDP, World Bank and private sector projects in Latin America, after relocating to Washington, DC for another four years (2015-2019), and briefly returning to Madrid (2020-2021) to work at Spanish multinational corporation ACCIONA.

This section covers the application of the DREI model to the Panamanian context, drawing on the UNDP (2013) report and the author's exposure. This is complemented by relevant case studies where the DREI framework was not formally applied or researched, but offers a potential contrast to Panama in its consideration of an alternative renewable energy source in another context.

One of the most significant site visits the author carried while at the World Bank was the Itaipu plant at the Brazil-Paraguay shared border in the Parana river basin. Large scale hydropower merited analysis in the context of the PhD thesis, both from the perspective of the DREI model, but also in contrast with the small-scale hydropower developments in England considered by the NWHRM.

It is an important contribution of this research, as it offered the possibility to understand the barriers to renewable energy deployment for the same NHWRM technology option (hydropower), but at a different scale. The location in another region outside of OECD countries provided the opportunity to introduce another EMDE context, this time outside of Sub-Saharan Africa. With transitions to clean energy taking different approaches worldwide, the research takes global relevance given that hydropower remains an alternative solution to South American gas-dependent countries.

4.2 Panama Onshore Wind Power

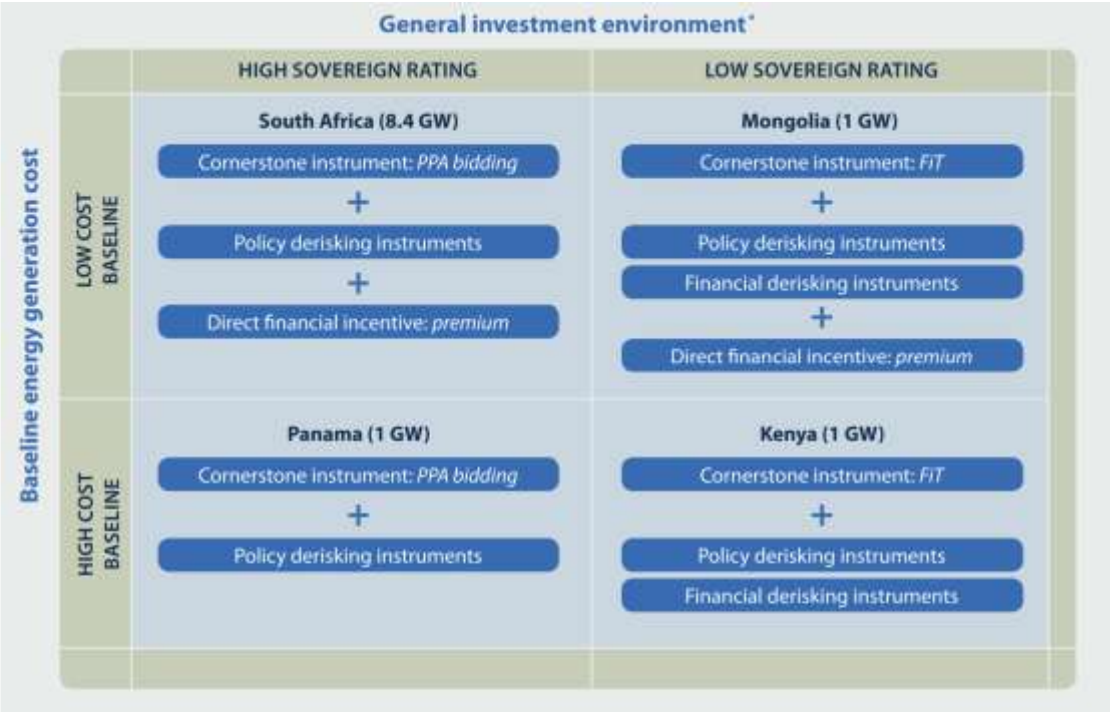
The DREI framework was applied to Panama in 2013. At the time, the author of not only contributed to the overall DREI report (UNDP, 2013), but also engaged with Panamanian developers and policymakers. It was both the CSP and other renewable energy deployment exposure in Namibia, South Africa and Sub-Saharan Africa that earned the author the role of Regional Technical Advisor for Climate Change Mitigation, with focus on energy, infrastructure, transport and technology, at the United Nations Development Programme Regional Service Centre for Latin America and the Caribbean, based in Panama. The author peer reviewed and contributed to the dissemination of the Panama case study.

The following draws on the desk and field research of the application of the DREI framework in Panama Onshore Wind Power. As noted earlier for the South Africa case, this application in Latin America sought to demonstrate the practical application of the model, with Panama chosen by UNDP as a country that would help assess a variety of renewable energy market conditions, including a different investment environment or baseline electricity generation costs. As part of adapting the framework the Panamanian context, the model made an assumption of a 20-year national target for wind investment of 1 GW, while in the South African case the long-term objective of 8.4 GW of was not assumed and instead the model used the actual announced goal by the government for 2030.

For instance, while South Africa offered a high sovereign rating with relatively low-cost electricity, primarily generated from inexpensive coal. Panama also sought to deploy onshore wind, as a mature renewable energy technology in Latin America, with reliable data and strong potential guaranteed price and market-access policies for wind energy, such as PPA-based bidding (UNDP, 2013). In assuming a 20-year national wind energy investment target of 1 GW in Panama, vis-à-vis the 8.4 GW target in South Africa, this model introduced a level of ambition to the exercise so it would be comparable across contexts – hence, the 1 GW target was also assumed for the Kenya and Mongolia cases outside of the scope of this PhD thesis. As a result, the findings across countries introduced a dimension of ambition or aspiration expected or assumed in different regions.

The DREI framework's instrument matrix was also used in the Panama onshore wind power case to select relevant policy and financial derisking measures. Just like in the South Africa case, financial derisking instruments were not considered given Panama’s high sovereign rating. In contrast, while South Africa’s model application considered a price premium, as its estimated levelised cost of energy for wind was higher than its baseline generation costs, no premium was considered for Panama as wind is cheaper than its baseline–see *Table 14* (below).

Table 15: DREI Model Country Contexts



General investment environment*

Baseline energy generation cost	HIGH SOVEREIGN RATING	LOW SOVEREIGN RATING
LOW COST BASELINE	South Africa (8.4 GW) Cornerstone instrument: *PPA bidding* + Policy derisking instruments + Direct financial incentive: *premium*	Mongolia (1 GW) Cornerstone instrument: *FiT* + Policy derisking instruments Financial derisking instruments + Direct financial incentive: *premium*
HIGH COST BASELINE	Panama (1 GW) Cornerstone instrument: *PPA bidding* + Policy derisking instruments	Kenya (1 GW) Cornerstone instrument: *FiT* + Policy derisking instruments Financial derisking instruments

Source: UNDP (2013)

As with other country cases also depicted (Kenya, Mongolia), but not covered in the author’s research, the DREI model application involved extensive data collection, including interviews with over 30 investors and stakeholders (UNDP, 2013). For comparison purposes, the UNDP report assumed wind technology costs were standardized across all countries, and factors like balancing costs, grid costs, and fossil fuel subsidies were excluded. The author’s own work and study throughout the research period shows these assumptions oversimplify country contexts (Alfaro-Pelico, 2022b), but this thesis acknowledges the relevance of the DREI model, and underscores the benefit of more detailed policy analysis and country consultations to further refine the application of this framework.

4.2.1 Panamanian Overview

The Panama case provided several practical insights, which compared to other Latin American cases not considered by the DREI report that the author was also exposed to, gave an illustration of the applicability of both DREI and NWHRM frameworks. They contributed to different perspectives to be considered by decision-makers assessing barriers to deployment of renewable energy.

In particular, policymakers were faced with different public instruments to scale up renewable energy. That said, these policy derisking measures alone do not automatically lead to catalysing private investment, which explain the need for complementary derisking instruments to address residual risks that these measures cannot single-handedly mitigate.

For instance, in Panama despite the existence of PPA bidding processes, a favourable investment climate, and lower wind energy costs than to the high-cost baseline, financial closure for wind energy projects was not initially achieved. Its "financing cost waterfall" (*Figure 24*, overleaf) revealed that non-price barriers existed, requiring further derisking efforts.

The modelling showed the need for additional derisking measures to boost investment, with a small amount of policy derisking potentially attracting up to 100 times its cost in private sector funds. Like in the South African and Namibian case, the transformation of renewable energy markets took time as barriers to investment were either tied to fossil-fuel reliance or deeply-rooted monopolistic market structures.

However, derisking instruments became a first step in a longer journey toward renewable energy market transformation, in line with NWHRM sequential decision making. The significance of derisking in lowering carbon abatement costs applied to all the case studies.

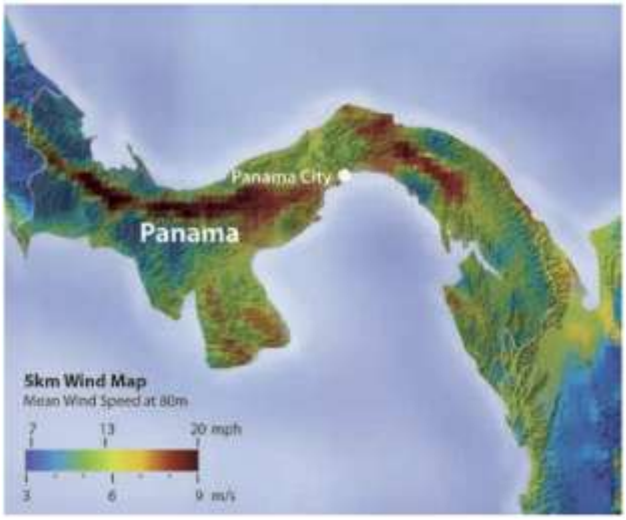
In particular, some countries aligned their national renewable energy policies with international climate change mitigation commitments, like the 2015 Paris UNFCCC Climate Agreement, or the UN Sustainable Development Goals for 2030.

It informed the different approaches and mechanisms countries took to deploy investments, and public finance instruments from multilateral climate funds like the Global Environment Facility and the Green Climate Fund.

As noted earlier, the DREI model Panama case envisioned an assumed 1 GW, 20-year wind energy investment target, where wind energy would play a key role in either meeting the country's rapidly growing electricity demand, or exporting power to neighbouring countries across Central America, Colombia, and Mexico.

On the domestic front, Panama's wind energy was well-suited to complement the country's hydropower, as the windiest months coincided with the dry season when energy costs were highest; or, an export-driven vision leveraging Panama's favourable investment climate or wind resources –see *Figure 22* (below):

Figure 22: Panama Wind Map

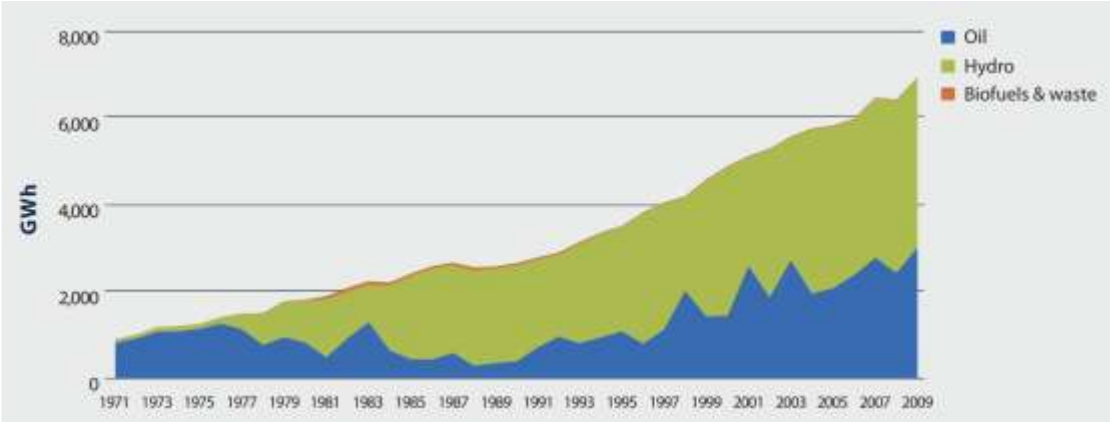


Source: UNDP (2013)

At the time of the application of the DREI model, Panama had an installed capacity of 1,320 MW, roughly evenly divided between thermal power and hydropower (UNDP, 2013).

Following major investments in hydropower during the late 1970s and 1980s, the latest investments had instead focused on oil-based power (bunker, diesel, and marine diesel) in line with a growing demand that was not satisfied by the existing renewable energy generation – see *Figure 23* (below):

Figure 23: Panama Power Generation Mix



Source: UNDP (2013)

Based on engagement with counterparts, the key driver for this latter development were their rapid deployment and low upfront cost requirement. However, Panama was left locked in high generation expenses, and a capacity only expected to just meet the peak demand at the time of 1,280 MW (ibid.).

In line with Panama's economic growth, demand was projected to grow at a high single-digit rate in the following years. The DREI model case study (UNDP, 2013) assumed a marginal baseline energy mix consisting of 62% heavy fuel oil and 38% hydropower, following the UNFCCC CDM methodology for determining marginal baselines. A grid emission factor of 0.435 tonnes of CO2 per MWh was estimated for that baseline. The case study applied a modelling algorithm to identify the best Panamanian sites, also assuming an average capacity factor of 43% for the 1 GW wind energy target. Additionally, a key assumption was that transmission lines and grid extensions to access the sites would be constructed.

While Panama was at the time drawing attention from several private sector wind energy developers and investors, no wind energy projects had yet been constructed. *Autoridad Nacional de Servicios Públicos* (ASEP), was the entity responsible for issuing generation licenses, having granted five: two totaling 330 MW to one developer, and three totaling 235 MW to another. ASEP was also reviewing and issuing provisional licenses for 17 additional wind sites, amounting to a further 1,484 MW in capacity.

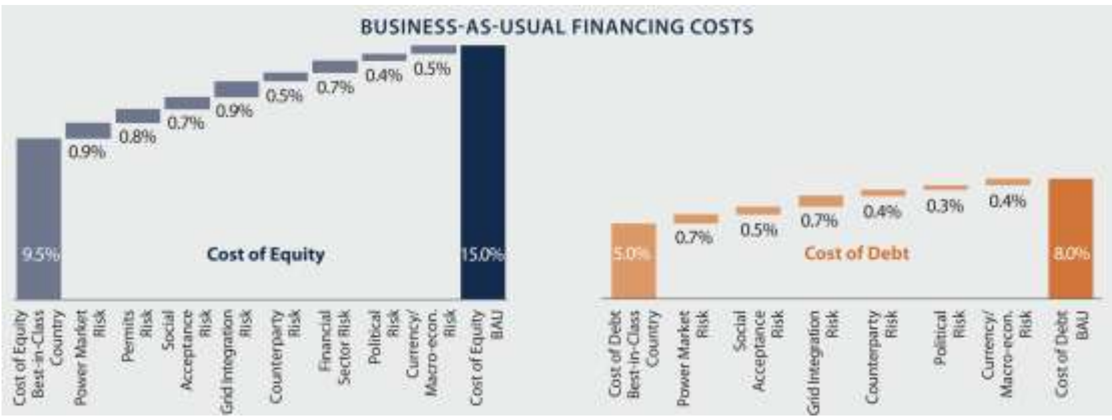
The state-owned transmission company, *Empresa de Transmisión Eléctrica S.A.* (ETESA), held its first exclusive wind tender in November 2011. The winning bidder, who had already secured 235 MW in generation licenses, submitted bids ranging US$ 9.5-11.0 cents per kWh, but by January 2013, no construction had begun on any sites. As a result, ETESA planned to launch its next tender in 2013.

4.2.2 Panama Risk Environment

For the DREI model case study, risk data was collected through interviews with wind energy project developers and investors who were either exploring or actively involved in Panama's wind energy sector. Additional interviews were conducted with other stakeholders.

The analysis of the risks contributing to higher financing costs for wind energy in Panama was illustrated in the risk waterfalls (see *Figure 24*, below), with risk categories identified as factors influencing higher financing costs including: power market risk, permitting risk, social acceptance risk, grid integration risk, financial sector risk, were identified as factors influencing financing costs; other risks included counterparty, political, and macro-economic risks, though they were deemed less significant.

Figure 24: Panama Wind Energy Financing Costs



Source: UNDP (2013)

With regards to the power market risk, investors acknowledged that the Panamanian government had made considerable strides in developing a regulatory framework for renewable energy.

Since the introduction of Law 6 in 1997, Panama had maintained an unbundled and liberalized energy market. Coordination across ministries improved with the creation of the *Secretaría Nacional de Energía* (SNE, or energy ministry) in 2008. Law 44, passed in 2011, also provided a legal framework to support wind energy development, and included tenders for 15-year PPAs with feed-in priority, along with incentives like exemptions from import tariffs on equipment and accelerated depreciation. Despite these advances, investors highlighted the need for continued liberalization and improvements in the regulatory framework.

Some generation and distribution companies remained partially government-owned, which investors suggested would create an uneven competitive environment. While transmission was managed by ETESA (Electricity Transmission Company), which operated the National Dispatch Center responsible for coordinating transactions between the various power generation and distribution companies, there were three distribution companies (EDERNET, EDECHI, and ENSA). Tariff regulation fell under the jurisdiction of ASEP.

Investors also noted that government officials, while knowledgeable about hydro-power, often lacked expertise in wind energy. As a result, investors faced higher-than-usual development costs when collaborating with government entities to establish suitable agreements, which direct linkages with permit risks.

Key permitting processes involved ASEP, issuing generation licenses and *Autoridad Nacional del Ambiente* (ANAM), granting environmental licenses. While the government was praised for establishing generally transparent procedures, investors noted a lack of coordination between government agencies, which contributed to significant licensing delays.

For instance, generation licenses required construction to begin within one year, but without regular tenders to secure power purchase agreements, this requirement became a significant barrier, leading to expired generation licenses and lengthy approval times for environmental impact assessments. These risks were also linked to those associated to grid integration and social acceptance.

Investors had a positive view of the dispatch centre, with personnel having been trained in Germany for intermittent power integration and management, and Panama's experience with grid balancing through hydropower. However, they expressed concern about the fact that grid management for wind energy was a completely new, unproven area in Panama.

Meanwhile, most promising wind sites were located on indigenous lands, making it a sensitive issue due to past cases of mistreatment of indigenous peoples in non-wind energy projects. However, investors believed that government awareness campaigns in the past had been successful, and they saw potential social benefits, such as improvements in health and education, for the impoverished communities involved in wind projects.

Some investors indicated that they mitigated these risks by ensuring that part of the carbon finance proceeds go to the community. Extensive stakeholder consultations, awareness campaigns, capacity building, and advocacy efforts would need to be conducted during project preparation and implementation to address those barriers.

This would need to include early involvement of decision-makers, including government stakeholders to provide overall direction, private sector and non-government organization stakeholders. These stakeholder groups would need to be brought together to discuss social, technical and environmental issues. Additional risks with moderate or low impact on financing costs included:

- *Counterparty Risk* – Investors cited several factors that made credit risk low or manageable, given Panama's competitive, liberalized energy market, foreign ownership by major international power operators (e.g., Italy's ENEL) and investment-grade sovereign rating.
- *Financial Sector Risk* – Local commercial banks were new to wind energy, but showed interest, with Panama boasting a large, developed financial sector with access to capital, and development banks were also keen to working with first-mover wind projects. Yet investors noted high transaction costs and lengthy processes to secure financing.

- *Political Risk* – Investors appreciated Panama's political stability and its reputation as a business-friendly environment.
- *Macro-Economic Risk* – Panama's economy was effectively dollarized, hence currency risks were minimized for investors. Confidence in the economy was bolstered by the Panama Canal expansion, despite concerns about inflation and reliance on the Canal-related and real estate sectors.

4.2.3 Panama Public Instruments

As Panama was considered an investment-grade country, the DREI case study assumed no need for financial derisking measures and instead applied a package of policy derisking instruments. The public cost of this policy derisking package was estimated at USD 20 million over the 20-year modelling period.

The country's traditional reliance on hydro and thermal power to meet its energy demand, required a shift toward private sector developments to utilise Panama's wind and solar resources. These efforts aligned with the government's plan to reduce dependency on imported hydrocarbons and enhance the reliability of the energy grid by diversifying power generation sources.

Laws No. 6 (1997) and 45 (2004) supported renewable energy promotion by stipulating that power transmission and distribution companies must give a 5% price preference to renewable energy sources in energy tenders.

New renewable energy sources (including hydro) up to 10 MW in capacity would be exempt from distribution or transmission charges, plants between 10 and 20 MW were exempt for the first 10 MW; and, equipment, machinery, and materials for renewable energy plants up to 500 kW would be exempt from import taxes.

Additionally, laws No. 6 (1995) and 10 (1998) established the regulatory and institutional framework for Panama's electric utility sector outlining:

(a) separation of the power sector into distribution, transmission, and generation companies;

(b) regulations for the creation and operation of public electric companies;

(c) rules for power company operations, tariff setting, and customer relations;

(d) modalities for private sector involvement;

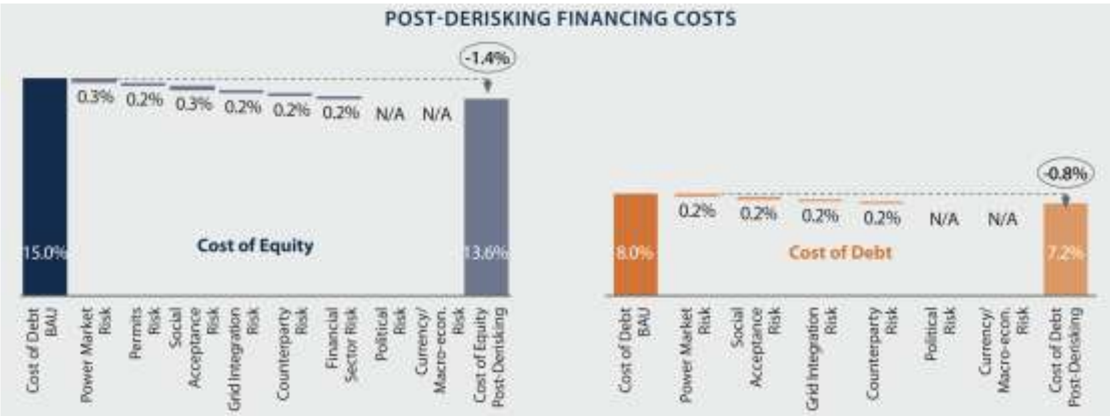
(e) provisions for environmental conservation;

(f) promotion of renewable, non-conventional energy sources and energy efficiency.

Renewable energy projects up to 10 MW would receive a fiscal incentive equivalent to 25% of direct investment, based on CO2 emissions reductions, which could be used for revenue tax payments during the first 10 years of operation, provided they did not benefit from other incentives.

The impact of these policy derisking measures on reducing financing costs for wind energy in Panama was depicted in *Figure 25* (below). The analysis suggested that these measures would lower the average cost of equity by 1.4% and the cost of debt by 0.8% over the 20 years:

Figure 25: Panama Wind Policy Derisking

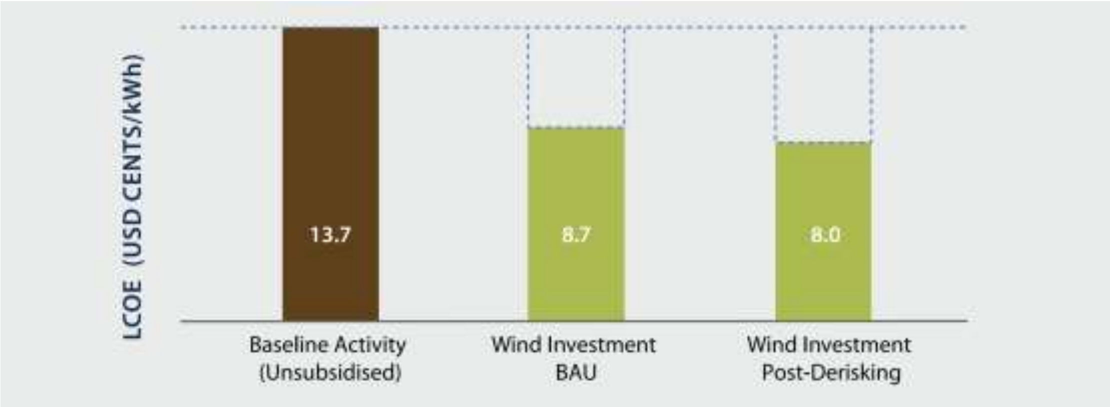


Source: UNDP (2013)

4.2.4 Panama Levelised Costs

The outputs of the DREI model application to the Panama case study in terms of Levelised Cost of Energy are presented in *Figure 26* (below); it showed that wind energy was more cost-effective than the country's unsubsidized marginal baseline; the current unsubsidized marginal baseline LCOE was calculated at US$ 13.7 cents per kWh:

Figure 26: Panama Baseline Versus Wind LCOE



Source: UNDP (2013)

Policy derisking reduced the LCOE for wind energy from US$ 8.7 cents per kWh (business-as-usual scenario) to US$ 8.0 cents per kWh (post-derisking scenario). Due to these negative incremental costs for wind energy, the modelling concluded that no financial incentives are needed.

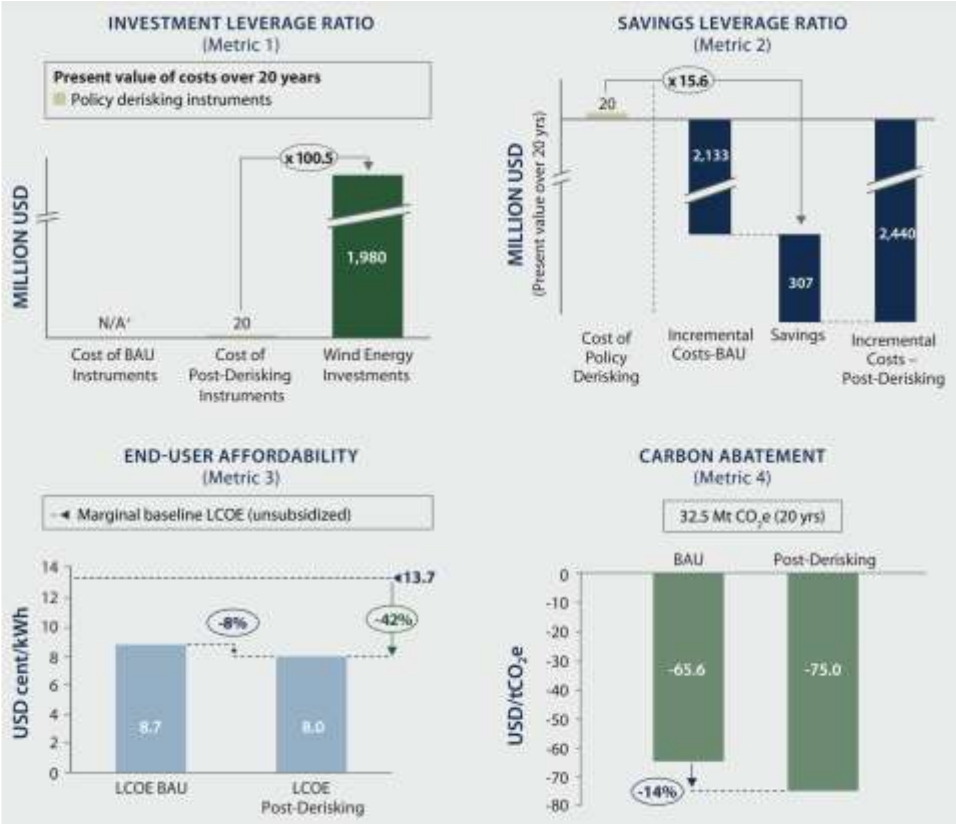
In comparison, a successful bidder from Panama's wind tender at the time offered prices between US$ 9.5 and 11 cents per kWh, higher than the model's business-as-usual scenario of US$ 8.7 cents per kWh (UNDP, 2013). According to UNDP, this discrepancy likely stemmed from the DREI model selection of more favourable wind sites (with higher capacity factors) based on assumptions regarding nearby transmission line availability.

4.2.5 Panama Evaluation

The sensitivity analysis shown in *Figure 28* (overleaf) computed how a lower wind capacity factor would result in a higher LCOE in the business-as-usual scenario. They highlighted the societal benefits of using policy derisking to address the underlying barriers to deployment of renewable energy, instead of financial derisking which in the Panamanian case would not be effective to overcome non-price barriers, nor to catalyse investment.

Despite being an investment-grade country able to generate wind power at lower costs than the marginal baseline, no private investment was yet happening in Panama. The performance metrics modelling the impact of derisking on its 1 GW wind energy investment target, are shown in *Figure 27* (below):

Figure 27: Panamanian Wind Power Metrics



Source: UNDP (2013)

Based on the author's own desk and field research, including discussions with private sector players, the lack of investment was more likely due to non-financial barriers. In the post-derisking scenario, these barriers would be removed through policy derisking, leading to a very high investment leverage ratio of 100.5x. Additionally, the case study showed a savings leverage ratio of 15.6x, meaning that a USD 20 million policy derisking package could unlock USD 2.4 billion in negative incremental costs over 20 years.

Challenges highlighted include a regulatory framework that was structured for dispatchable energy sources like coal, gas, oil, and hydroelectricity, which did not provide incentives for new wind projects. Energy planning also faced increasing variability and uncertainty due to the anticipated high levels of wind generation. Additionally, flexibility, system adequacy and stability challenges associated with integrating large amounts of wind that would require adjustments to existing operational practices and identification of flexibility mechanisms. Individual and institutional capacity and workforce development challenges were also noted.

The DREI model Panama case sensitivity analyses for the wind energy capacity factor and marginal baseline fuel costs are presented in *Table 16* (below). For example, in terms of affordability (which measured the incremental cost per kWh), a 10% increase in the wind capacity factor in the post-derisking scenario was assessed to lead to a 13% increase in savings. The investment leverage ratios would remain unchanged in the sensitivity analyses for both metrics, as there was no price premium in Panama:

Table 16: Panamanian Wind Power Sensitivity

	SENSITIVITY ON WIND CAPACITY FACTOR						
	INVESTMENT LEVERAGE RATIO		SAVINGS LEVERAGE RATIO	AFFORDABILITY (INCREMENTAL COSTS USD/kWh)		CARBON ABATEMENT (USD TONNE CO_2e)	
Base case	BAU	N/A	15.6x	BAU	-\$0.05	BAU	-\$65.59
	Post-Derisking	100.5x		Post-Derisking	-\$0.06	Post-Derisking	-\$75.02
+10% Capacity Factor	BAU	N/A	15.6x (0%)	BAU	-0.06 (-15.9%)	BAU	-76.05 (-15.9%)
	Post-Derisking	100.5x (0%)		Post-Derisking	-0.06 (-12.8%)	Post-Derisking	-84.62 (-12.8%)
-10% Capacity Factor	BAU	N/A	15.6x (0%)	BAU	-0.04 (19.5%)	BAU	-52.81 (19.5%)
	Post-Derisking	100.5x (0%)		Post-Derisking	-0.05 (15.6%)	Post-Derisking	-63.29 (15.6%)

	SENSITIVITY ON FUEL COSTS						
	INVESTMENT LEVERAGE RATIO		SAVINGS LEVERAGE RATIO	AFFORDABILITY (INCREMENTAL COSTS USD/kWh)		CARBON ABATEMENT (USD TONNE CO_2e)	
Base case	BAU	N/A	15.6x	BAU	-\$0.05	BAU	-\$65.59
	Post-Derisking	100.5x		Post-Derisking	-\$0.06	Post-Derisking	-\$75.02
+10% Fuel Costs	BAU	N/A	15.6x (0%)	BAU	-0.06 (-17.9%)	BAU	-77.33 (-17.9%)
	Post-Derisking	100.5x (0%)		Post-Derisking	-0.07 (-15.6%)	Post-Derisking	-86.75 (-15.6%)
-10% Fuel Costs	BAU	N/A	15.6x (0%)	BAU	-0.04 (17.9%)	BAU	-53.86 (17.9%)
	Post-Derisking	100.5x (0%)		Post-Derisking	-0.05 (15.6%)	Post-Derisking	-63.29 (15.6%)

Source: UNDP (2013)

Overall, the performance metrics in Panama show roughly equal sensitivity to both the wind capacity factor and fuel costs. This could be attributed to Panama's high-cost marginal baseline, which was largely dependent on heavy oil. As a result, fuel costs played a significant role in the affordability and carbon abatement metrics, reducing the influence of other usually important factors, like the wind capacity factor. The removal of barriers for deployment of renewable energy required policy derisking actions including nationwide energy planning.

4.2.6 Panamanian Insights

This case study underscored various risks linked to hydropower. As *Figure 23* (above) showed, the Panamanian power generation matrix was largely dominated by this renewable energy resource. Most importantly, the country's reliance on hydropower increased its power market risk since investors noted government counterparts where only familiar with this technology, as one of the challenges in the introduction of wind energy. This familiarity also affected permit risks, since ANAM as the Panamanian environmental agency was mostly exposed to licensing related to hydropower. In addition, grid integration risks were not only linked to Panama's need for renewable energy balancing with hydropower, but also the lack of exposure to the unique operational challenges of variable wind and solar power.

The DREI framework had only been applied to wind and solar power. The author contributed to the UNDP (2013) report not only drawing on his renewable energy experience, but also broader exposure to climate change mitigation and adaptation across sectors. This expertise included hydropower development, which is not the renewable energy technology of choice for the DREI model, but features directly or indirectly in its assessment of barriers and management of risks to deployment of other sources. The DREI model did cover the variability of renewable energy, but in the author's view it was approached as a natural hazard of wind or pattern of solar energy (its seasonal or temporal nature partially addressed with storage), rather than as a climate risk, which based on experience is particularly relevant to hydropower.

As Regional Technical Advisor for Energy, Infrastructure, Transport and Technology at the United Nations Development Programme Regional Hub for Latin America and the Caribbean, based in Panama, the author provided technical assistance, capacity building and led the mobilization of climate finance across sectors including hydropower. The expertise drew from its exposure to climate resilience developments in Namibia, which affected its Ruacana Power Station. This experience with the climate change adaptation and landscape restoration elements of hydropower was replicated in the next case study in Latin America.

4.3 Paraguay Large Scale Hydropower

The author was involved in the promotion and awareness raising of climate vulnerability and adaptation issues affecting the energy sector, which became a prominent feature of his Latin American exposure later on, as Practice Manager for Environment and Natural Resources at the World Bank. The author supported directly and indirectly the removal of barriers of renewable energy in Brazil, and specially Paraguay where he oversaw a landscape restoration project.

4.3.1 Paraguayan Overview

Paraguay remains a global leader in renewable energy use, with hydropower supplying the majority of its electricity. The country successfully implemented bi-national power generation projects, due to the vast potential provided by the Paraná and Acaray rivers, as well as the tributaries it shares with neighboring countries (including Argentina and Brazil). The development of the country's electricity sector is managed by the National Electricity Administration (*Administración Nacional de Electricidad*, or ANDE), a vertically integrated state-owned enterprise that made significant investments in infrastructure to ensure universal access to electricity for the Paraguayan population. ITAIPU as the largest hydropower plant in Latin America, and the second largest globally with a capacity of 14,000 megawatts became the author's focus of study and research.

Given Paraguay's dependence on ITAIPU, this plant also carried a strong environmental mandate that the author contributed to while overseeing his lending and capacity building portfolio at the World Bank. The conservation of the Upper Paraná River Basin, reduction of erosion that would impact plant operations and addressing the ecological and social impacts caused by its construction decades ago became one of the projects under his oversight. The GEF-funded and World Bank-supported "Sustainable Forest Management: Improving the Conservation of Biodiversity in Atlantic Forest of Eastern Paraguay" project contributed to ITAIPU and the government efforts to reduce the deforestation rate, and associated biodiversity loss within the productive landscape and related watershed of the Paraguayan Atlantic Forest (GEF, 2010).

ITAIPU owned approximately 70,000 hectares of Atlantic forest along the reservoir's shore, representing the largest forest corridor in the country, stretching over 1,500 km; additionally, it led Paraguay's largest restoration initiative through its Preserva Program, which aimed to reforest 2,060 hectares of degraded land with native species (ibid.). As part of this project, all ITAIPU reserves were included in the corridor and its related watershed.

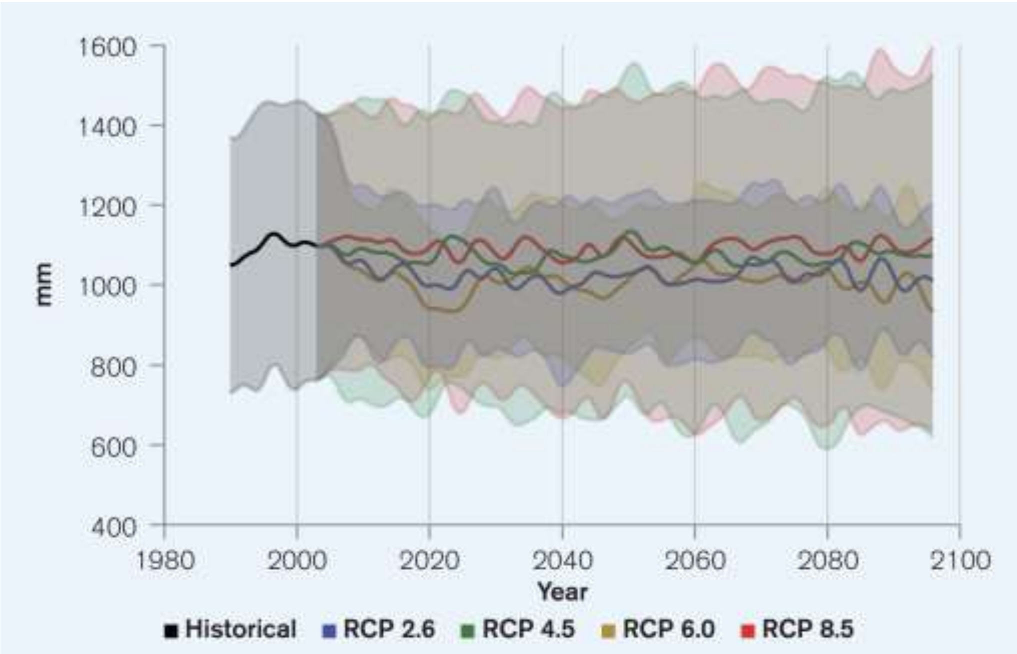
The dam still provides most of Paraguay's electricity and generates significant foreign exchange through the sale of surplus power to Brazil. Not only it made ITAIPU a major source of Paraguay's public revenue, but also a prominent renewable energy source in Latin America, which the author deemed worth researching. Hydropower was an uniquely Latin American feature of renewable energy deployment contributing to the region's sustainable energy future. Beyond its climate change mitigation contribution, alongside other renewable energy sources considered by the DREI model (solar and wind), the author saw the need to consider the climate change adaptation considerations of hydropower, and how watershed protection through sustainable forest management could strengthen its resilience to a changing climate globally.

4.3.2 Paraguay Risk Environment

Climate change was affecting the country's power generation, impacting both supply and electricity export revenues. Paraguay's economic dependence on hydroelectric energy production was particularly susceptible to the effects of rising climate variability and climate change – this was exacerbated by the country's high deforestation rate, largely driven by the agriculture and livestock industries. According to the World Bank (2021), gradual changes in precipitation patterns, with reduced average rainfall, impacted the hydropower resource base by decreasing runoff and river flows, affecting the volume and timing of water availability. For instance, before the author joined the World Bank in 2015, droughts linked to a La Niña event and reduced water flow on the Paraná River, caused an 8.7% drop in output at the Itaipú dam (ibid.). Higher temperatures also led to increased evaporation, reducing water levels in reservoirs, while heavy rainfall resulted in floods that damaged critical energy infrastructure.

Hence, the merits of applying the DREI model to Paraguay. Based on historical data and forecast projections, rainfall in Paraguay would experience considerable interannual variability – see *Figure 28* (below). This was due to El Niño Southern Oscillation, which could lead to floods and cooler conditions, and La Niña linked to droughts and warmer weather. Indeed, projections indicated a significant increase in average monthly precipitation during the austral winter months (June to August), especially in the northern, eastern, and southeastern regions:

Figure 28: Paraguay 1986-2099 Annual Average Precipitation



Source: WB (2021a)

Conversely, precipitation during the austral summer months were expected to either remain steady or slightly decrease in the northeastern areas. Additionally, maximum rainfall totals over a five-day period were anticipated to see a slight rise throughout the 21st century. Therefore, there was considerable uncertainty regarding future rainfall patterns in Paraguay, with most scenarios suggesting an average projected increase in annual precipitation by the end of the century under a high emissions scenario (WB, 2021). These projections also indicated notable regional variability, where rising runoff levels in parts of the country were expected to exacerbate the risk of floods and landslides, as well as increase the frequency of natural disasters like droughts. It underscored the importance of diversifying the energy mix beyond hydropower technologies.

However, Paraguay's reliance on fossil fuels had increased, leading to higher greenhouse gas emissions from the energy sector negatively impacting its energy security and climate goals. This shift toward fossil fuels was mainly driven by the transport sector, highlighting the need for deploying renewable and low-carbon technologies beyond power generation to help decarbonize the energy sector. The country's ethanol and biodiesel industries counted as sustainable energy sources, supplying around 7% of the fuel needed for road transport.

That said, the author’s field visit to ITAIPU underscored the need to account for climate resilience, landscape restoration and watershed management considerations. These considerations were largely missing from the assessment of barriers and mitigation of risks of the original DREI framework. However, they were inherently part of the ecological implications of the NWHRM approach. Indeed, Paraguay faced significant environmental challenges, which were complex to address due to its economic model focused on primary production and agro-industry. It exerted considerable pressure on natural resources.

As the GEF (2013b) had assessed, the expansion of Paraguayan agriculture, coupled with domestic and international demand for wood, led to widespread deforestation. This deforestation not only reduced forested areas but also caused soil erosion, contamination of rivers and streams, and impacted biodiversity, including the quality of life of indigenous communities. Soil quality further degraded due to extensive pesticide use, monocropping practices over several decades, and slash-and-burn activities, which also harmed water resources.

In addition, environmental management issues assessed by the GEF (2013b) included weak technical and institutional capacity, limited engagement from relevant stakeholders at national and especially local levels, lack of cross-sector coordination on environmental policies and programs, and inadequate monitoring and evaluation. A key need was to build capacity for managing environmental data, as expertise from non-state actors was not sufficiently integrated into decision-making processes. Research from universities and institutes remained isolated and the author’s own involvement as a researcher only coincided with his role at a public finance decision-maker, the World Bank.

The author visited the Upper Paraná Atlantic Forest, which was the largest eco-region within the Atlantic Forest complex adjacent to ITAIPU. It was an internationally recognized biodiversity "hotspot", one of the “Global 200” Eco-Regions shared by Argentina, Brazil, and Paraguay, part of a biome critically endangered by extensive land conversion reduced to less than 7% of its original size – with Paraguay holding the largest share of the Atlantic Forest encompassing about 1.3 million hectares of native forest, while deforestation severely diminished area and connectivity of its remaining forest (GEF, 2010).

Key drivers of deforestation and biodiversity loss included: (a) government policies and legal frameworks that inadvertently might have encouraged deforestation; (b) inadequate countermeasures against escalating land clearing for timber, livestock, and industrial soybean farming; (c) insufficient enforcement of environmental laws, poor planning coordination at national and local levels, and political and economic policies straining natural resources. The deforestation led to severe soil erosion, reduced soil fertility, and declining water resources, impacting local livelihoods and agricultural productivity, particularly within the ITAIPU reservoir catchment area where the situation was very critical.

In addition to the impact of nature and climate risks to hydropower generation capacity, the research also considered risks associated to Paraguay’s investment needs in transmission and distribution (T&D). In the aftermath of the 2008 financial crisis, the country also needed to invest in ANDE, as part of its efforts to strengthen public institutions in the electricity sector (World Bank, 2010).

As IRENA (2021) showed, while the country’s peak power generation capacity (8.8 GW) was more than 4 times its domestic peak demand (1.9 GW), Paraguay still faced inefficiencies in the energy sector, challenges in transparency and optimization of electricity service provision, and losses in transmission and distribution. The country's electricity demand was driven by rising residential and commercial usage, yet constrained existing challenges in the electric system (e.g., limited network capacity, poor service quality, low collection rates). Despite its substantial generation capacity, Paraguay struggled with providing reliable and high-quality electricity services, and lack of effective metering systems.

The country was plagued by frequent outages and voltage fluctuations, which the author still witnessed in its site visit. The transmission system's maximum capacity of 1,700 MW was already exceeded in 2009 when peak demand reached 1,810 MW – then, customers experienced an average of 16.9 outages, each lasting around 11.4 hours (WB, 2010). These disruptions were primarily due to transmission assets operating near their thermal limits, causing system shutdowns in response to shocks. However, they were also impacted by weather conditions like hot summers, heavy rains, and thunderstorms exacerbated by climate change, which often triggered the activation of protection devices on transmission lines leading to service interruptions. In addition, the long distances between generating plants and load centres—approximately 300 km—contributed to voltage fluctuations, adversely affecting businesses and households. Thus, to prevent potential supply crises and improve the quality and reliability of electricity services, ANDE urgently needed additional transformation and reactive compensation capacity to bolster T&D resilience.

4.3.3 Paraguay Public Instruments

The ITAIPU dam is one of the world's largest infrastructure projects. It is the second largest hydropower plant in the world by installed capacity (14,000 MW) – see *Table 17* (below), but largest by annual output depending on the year and its climate in comparison with the first largest Three Gorges Dam (22,500 MW) due to their different seasonality (WEF, 2022). The ITAIPU Dam generates a comparable amount of energy given the Parana River's more stable flow, and lesser seasonal fluctuations throughout the year than that of the Yangtze River.

Table 17: World's Large Hydro Dams

Country	Dam	River	Installed Capacity (gigawatts)	Dimensions (meters)
China	Three Gorges Dam	Yangtze River	22.5	181 x 2,335
Brazil / Paraguay	Itaipu Dam	Parana River	14.0	196 x 7,919
China	Xiluodu Dam	Jinsha River	13.9	286 x 700
Brazil	Belo Monte Dam	Xingu River	11.2	90 X 3,545
Venezuela	Guri Dam	Caroni River	10.2	162 x 7,426

Source: WEF (2022)

As the Three Gorges Dam experiences a significant drop in flow for several months annually, the natural ecosystems play a key role in any dam's functionality. For ITAIPU, the maintenance of low sediment levels in the reservoir was key, with interventions that would protect the turbines and help sustain efficient operations not limited to the physical but also natural infrastructure. This derisking intervention the author was overseeing was critical to conserve and restore the Parana river ecosystems, including its landscapes and watersheds, to mitigate and adapt to climate change impacts, and to demonstrate both financial viability and socioeconomic benefits to communities.

The conservation of biological diversity was financed through the GEF-funded, World Bank-supported USD 4.5 million Sustainable Forest Management in Atlantic Forest of Eastern Paraguay project (GEF, 2010). The project supported Paraguay's efforts to balance sustainable natural resource-based economic development with the conservation of forest biodiversity, establishing a conservation corridor to reconnect large forest remnants through a micro-catchment-based approach to natural resource management. The corridor covered five departments in eastern Paraguay (Alto Paraná, Canindeyú, Caaguazú, Itapúa, and Caazapá). The project's strategy included strengthening public and private protected areas within the corridor, offering technical and financial support to farmers in these micro-catchments, and enhancing public institutions' capacity for monitoring, enforcement, and the development of policies for biodiversity conservation in the Paraguayan Atlantic Forest.

In addition, natural resource management interventions were supported by a blended USD 137.5 million loan from the IBRD-funded Sustainable Agriculture and Rural Development Project (PRODERS) and Itaipú Binacional resources (WB, 2007). PRODERS provided grants and technical assistance in micro-catchments within the project areas, while Itaipú Binacional's resources were allocated to other parts of the conservation corridor. Recognizing the inevitable trade-offs involved in large-scale hydropower projects, these derisking interventions underscored the need to carefully balance community and environmental impacts with the benefits of clean energy generation.

4.3.4 Paraguay Levelised Costs

Subsequent programs like the Itaipú Preserves program conducted cost-benefit analyses yielding a Net Present Value (NPV) of $45 million based solely on direct financial benefits from these types of efforts. The analyses compared the costs of implementing derisking interventions such as trees, labour, monitoring, and maintenance for almost a decade against the avoided dredging costs that would have been incurred without the program. These estimations also factored in the benefits of watershed restoration, including enhanced water supply contributing to increased electricity generation capacity. The program cost $9 million, demonstrated significant long-term value and confirmed that Itaipú would have faced higher dredging expenses and reduced electricity generation based on the 184-year remaining lifecycle of the dam starting from 2014 (IDB et al., 2020).

Beyond direct financial gains, the restoration efforts provided numerous co-benefits not included in the analyses, including potential economic opportunities such as carbon sequestration, which could be monetized through carbon credits, and biodiversity habitat restoration, which could support eco-tourism. The conservation and reforestation of 101,000 hectares captured 5.9 million tons of CO_2 annually, contributing to climate change mitigation; the reforested buffer zones also offered protection against local climate extremes like storms and high winds, while the river and reservoir provided flood mitigation services (ibid.).

According to latest Paraguayan assessments, in 2018 the national average electricity rate was the lowest in Latin America with the cost of hydropower generation approximately at US$ 5.7 cents per kWh, and an average sales price stood at US$ 6.4 cents per kWh, resulting in a 12% surplus; public sector electricity tariff averaged US$ 4.9 cents per kWh, while residential electricity averaged US$ 6.9 US cents per kWh (ibid.). Given Paraguay's electricity exports experienced a decline over recent years, on the one hand, because of rising domestic consumption and, on the other, dry hydrological conditions in the Paraná River Basin, the post-derisking benefits of both climate mitigation, ecosystem restoration and resilience infrastructure implementation also show up in terms of LCOE. Other metrics assessed also helped illustrate these benefits.

4.3.5 Paraguay Evaluation

This case study highlighted innovative approaches to enhancing the resilience of large infrastructure developments. Despite the challenging environmental situation, a positive shift took place since 2004 due to measures by the Government of Paraguay. These measures include the adoption of a National Environmental Policy prioritizing natural resource conservation, the enactment of the Zero Deforestation Law (Law 2.524/04), the strengthening of the Secretariat of Environment, and a natural resource management program by the Ministry of Agriculture, with partial funding from the World Bank.

As a result, deforestation rates dropped significantly in 2005 and 2006. The Zero Deforestation Law, effective through 2008, prohibited land-use changes in forested areas of eastern Paraguay, creating a supportive environment for further biodiversity conservation efforts in the Paraguayan Atlantic Forest. The project became a collaborative effort among SEAM, MAG, and Itaipú. Itaipú then expanded its conservation and rural development initiatives around its reservoir and planned to contribute both financially and operationally to this project. The Itaipu case provided insights and perspectives for a more comprehensive management of climate risks, with more clarity on industry practices in hydropower development and operations.

For instance, as part of the initial phase of the GEF-funded biodiversity project, over 3,000 small farmers participated in reforestation efforts, planting native tree species across more than 125,000 hectares; conservation efforts in the Atlantic Forest, home to Guaraní ethnic groups, including the Mbyá, Ava, Aché, and Pai Tvytera were also supported; 55 communities, comprising over 10,000 residents were actively involved in implementing the (WB, 2017).

The project preserved the Atlantic Forest by focusing on four key objectives: (i) promoting sustainable use of native forests and protecting watersheds, (ii) restoring landscapes and regenerating forests, (iii) implementing socio-productive environmental programs, and (iv) sharing benefits with indigenous communities while contributing to climate change mitigation and adaptation.

In addition, to safeguard water quantity and quality, Itaipú established an extensive environmental conservation area, planting over 44 million trees, which resulted in the protection of more than 100,000 hectares, encompassing reserves, wildlife refuges in both Brazil and Paraguay, and a biological forest corridor that shields the reservoir (UNFCCC, 2017).

Itaipú became the world's first hydroelectric facility to have its protected areas and surrounding landscapes recognized by UNESCO as a Biosphere Reserve. Yet, while forest conservation became a critical derisking measure for securing water resources, the project interventions also addressed land-use practices. This is due to its location in one of the most agriculturally productive regions of Brazil and Paraguay, therefore facing environmental threats to its water systems.

In effect, measures such as terracing farmland to manage rainfall drainage and improve soil water retention; promoting no-till planting to reduce pesticide reliance and maintain soil coverage; and, repurposing livestock waste into biogas for energy and biofertilizers enabled Itaipú to achieve a record annual energy generation of 103.1 million MWh in 2016, i.e., an equivalent amount of energy from a thermal source would have required 583,000 barrels of oil per day (ibid.).

In line with the spirit of both DREI model and NWHRM approaches, an analysis of costs and benefits of the GEF-funded, WB-supported project showed its tangible, intangible, quantitative and qualitative impacts–see *Table 18* (below). They range from climate adaptation, ecosystem restoration and hydropower generation, and show addressing barriers of renewable energy also have an interdisciplinary dimension (including social inclusion and income generation):

Table 18: Paraguayan Hydropower Impacts

	Tangible	Intangible
Direct	• Improved forest management • Tourism • Sustainable timber use	• Biodiversity conservation • Reduction in GHG emissions • Reduction in deforestation
Indirect	• Increased resilience to external shocks • Improved watershed services (for example, for drinking water, hydropower generation, and others)	• Reduction in soil erosion • Enhancing institutional mechanisms in support of decentralization and delivery of public services by the Forest Administration • Strengthened self-governance capacity of communities and community groups • Regulatory frameworks for forestry are in place

Source: WB (2017)

In this Paraguayan case study, the author witnessed how the promotion of sustainable forest management, protection of biodiversity from the landscape to the riverscape, including the author's own planting of a tree, and restoring of fish habitats, and inclusion of small-scale farmers in conservation yielded positive impacts, quantified in *Table 19* (below):

Table 19: Paraguayan Hydropower Sensitivity

	Baseline		Baseline (-20%)		Baseline (-50%)	
	NPV	BC-Ratio	NPV	BC-Ratio	NPV	BC-Ratio
Discount Rate 5%	1,349,174,384	6.60	1,031,133,343	5.28	395,051,263	2.64
Discount Rate 10%	881,530,976	6.43	672,739,800	5.14	255,157,447	2.57
Discount Rate 20%	459,195,995	6.09	349,310,868	4.87	129,540,612	2.44

	Baseline		Baseline (-20%)		Baseline (-50%)	
	NPV	BCRatio	NPV	BC-Ratio	NPV	BC-Ratio
Discount Rate 5%	1,112,389,706	7.09	853,380,083	5.67	335,360,835	2.84
Discount Rate 10%	786,236,585	7.09	603,168,690	5.67	237,032,899	2.84
Discount Rate 20%	448,302,271	7.09	343,919,246	5.67	135,153,195	2.84

Note: NPV = Net Present Value; BC-Ratio = Benefit Cost Ratio

Source: WB (2017)

The cost-benefit and sensitivity analysis (above) carried out by the World Bank (2017) assessed the economic efficiency of the project considering different discount rates (i.e., 5%, 10%, and 20%), and baselines of economic benefits (i.e., from 0% to reductions by 20% and 50%), considering funds from all project counterparts (first table) and only from the GEF (second table).

In all scenarios, the project was economically feasible with different net present values, and benefit-cost ratios, by more than six times (at the lowest rate the NPV exceeding USD 1 billion. When only GEF contributions are considered, the results remained favourable. These quantitative findings were complemented with an assessment of qualitative benefits, amongst these, the strengthening of institutional capacities at central and local levels, and of different private and public actors.

4.3.6 Paraguayan Insights

The field research showed that while ecosystems appear to be undervalued when considering hydropower developments (beyond the obvious need for water), their sustainable management reap more benefits than electricity generation.

As with other natural resources often seen as public goods, their value might end up being under- (or not at all) priced. It is a step beyond the more widely accepted focus on environmental safeguards, and “do-no-harm” approaches, that is equally important to prevent degradation, other market failures and externalities. Paraguay represents one of the world’s most hydro-dependent electricity systems, with over 99% of national power generation derived from hydropower, primarily through the ITAIPU, Yacyretá, and Acaray complexes. Its leadership as an energy exporter is vulnerable to the following vulnerabilities:

a. Hydrological Variability – Reduced and irregular rainfall in the Paraná River Basin driven by climate change, which directly affects reservoir inflows and generation capacity. Lower river flows translate into revenue volatility, since export earnings from ITAIPU depend on generation output.

b. Overreliance on a Single Resource – Heavy dependence on large hydro assets limits its flexibility to respond to climatic variability, which creates a systemic risk as drought years simultaneously reduce domestic supply and export income.

c. Transboundary Governance Vulnerability – The joint management with Brazil carries bilateral political and operational risk, such that hydrological stress might lead to diplomatic tensions over energy pricing and treaty renegotiation.

d. Environmental and Social Fragility – The flow regime changes affect downstream ecosystems and local communities dependent on fishing, irrigation, and floodplain agriculture, with impacts that can erode the social license to operate, as well as potentially delay maintenance and reinvestment decisions.

For the DREI model to assess hydro-specific risk dimensions, the framework would need to specifically consider: (a) hydrological risk, thus integrating climate-hydrology forecasting, water balance simulations, and flow variability indicators; (b) environmental and social acceptability risk, thus capturing new dimensions such as ecosystem services, displacement or social equity; (c) transboundary risk, hence bringing in cross-border compliance, coordination and governance dimensions; (d) coverage risks, noting the need to consider liquidity, insurance and payment risks linked to water availability.

5 Evaluation of Barriers in Central Asian Countries Applying the Derisking Renewable Energy Investment Model

5.1 Central Asian Context

The DREI framework introduced in 2013 was original applied to one country in Central Asia. With expanded focus on climate resilient hydropower from field research in Latin America, the author saw the value of considering the applicability of both NWHRM and DREI approaches to a different region.

This regional consideration is relevant because of the thesis focus, on the one hand, on applying the former approach to different sources, scales and sites for renewable energy deployment. On the other hand, the identification of additional barriers not considered by either model shows there are other risk-return dimensions, and derisking instruments to address them to unlock investment.

The author's research experience in this region builds on the ecosystem restoration and climate change adaptation aspects assessed in the Americas. The thesis so far has looked at Latin America within that region, but will also weigh in on the Caribbean, to see how the application in SIDS might help distil other barriers and constraints in EMDEs.

They might be linked to the comparatively smaller scale of deployments vis-à-vis larger countries, and different vulnerability considerations for similar (e.g., hydro or solar) renewable energy sources. But in Central Asia the size of deployment might be somewhat comparable. The following Mongolia DREI case study serves as a desk research benchmark for the field research the author undertook in Tajikistan, in his role as manager of the World Bank's share of the Pilot Program for Climate Resilience (PPCR) – one of the climate finance mechanisms under the Climate Investment Funds (CIF) – and global lead climate change specialist.

5.2 Mongolia Onshore Wind Power

The DREI Mongolian case considered the feed-in-tariff (FiT) as a different cornerstone instrument to assess policy or financial derisking measures to power-purchasing agreement (PPA) based bidding of both South Africa and Panama.

Part of the rationale for FiTs was the lower sovereign ratings of Mongolia (and Kenya) approach, with the key role expected from financial derisking interventions, or event direct financial incentives to attract investors.

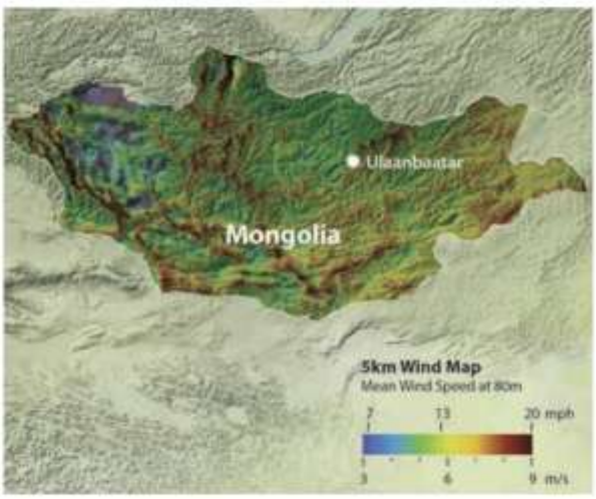
Same model assumptions were considered as with the other DREI cases codified in 2013, including 20-year national targets for wind investment, investors and other stakeholder interviews. But the low-cost baseline was distinctive for the Kenyan and Mongolian case, as the cost of renewable energy was less competitive than conventional alternatives (UNDP, 2013).

5.2.1 Mongolian Overview

The DREI model Mongolia case also envisioned a 1 GW, 20-year wind energy investment target, where wind energy could play a key role in the country's rapidly growing electricity demand coming out of a Soviet-era, centrally planned economy to a more market-based economy that experienced growth driven my its mining industry.

In such context, the low-case baseline associated to a coal-based power generation needed to be contrasted with its aging infrastructure. Like other countries, Mongolia found itself in a trade-off between established hydropower technologies, to the country's wind potential –see *Figure 29* (below):

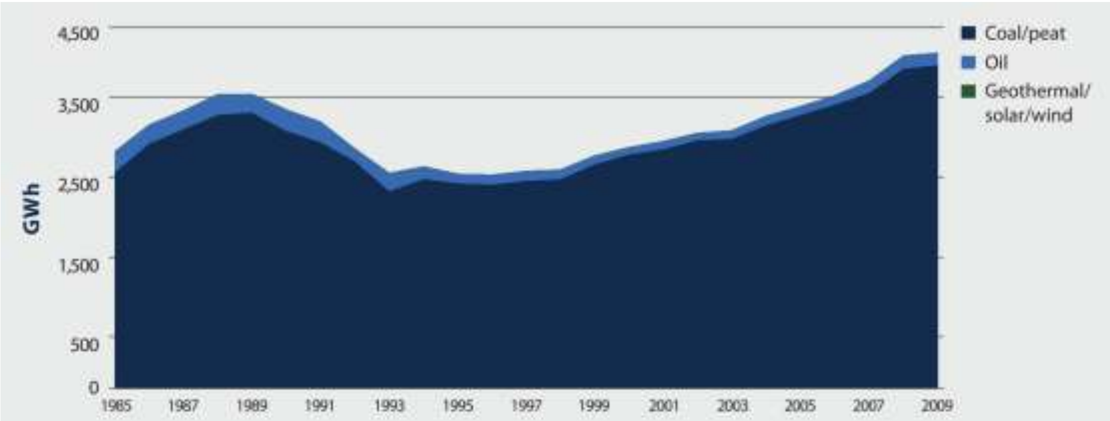
Figure 29: Mongolia Wind Map



Source: UNDP (2013)

Mongolia had an installed energy capacity of 1,050 MW, with only 728 MW operational due to losses from aging plants and transmission infrastructure, in a predominantly fossil fuel-based (coal) electricity matrix – see *Figure 30* (below); however, the country possessed abundant wind, hydro, solar, and geothermal power resources (UNDP, 2013). Of these sources, wind energy potential (300 GW) was particularly notable, with prime locations scattered across the country. as depicted in *Figure 29* (above), in the South Gobi Desert region (ibid.).

Figure 30: Mongolia Power Generation Mix



Source: UNDP (2013)

From a demand perspective, the same region is also home to Mongolia's largest mines, strategically positioned for energy exports to China. Therefore, had garnered interest from private sector investors and developers in wind energy, including for projects such as the 50 MW Salkhit wind farm, 70 km southeast of the country's capital, Ulaanbaatar. This project had secured a license, a long-term PPA, and financial derisking support from development banks. Other projects in the pipeline with a PPA included a 250 MW wind farm in the Gobi Desert.

This project tested DREI's capacity to address non-technical investment barriers in an emerging market with high wind potential but low private investment readiness. The country's context included extreme climatic conditions, with harsh winters and strong wind variability; nascent policy and regulatory frameworks for independent power producers; limited grid infrastructure; and lack of financial depth.

5.2.2 Mongolia Risk Environment

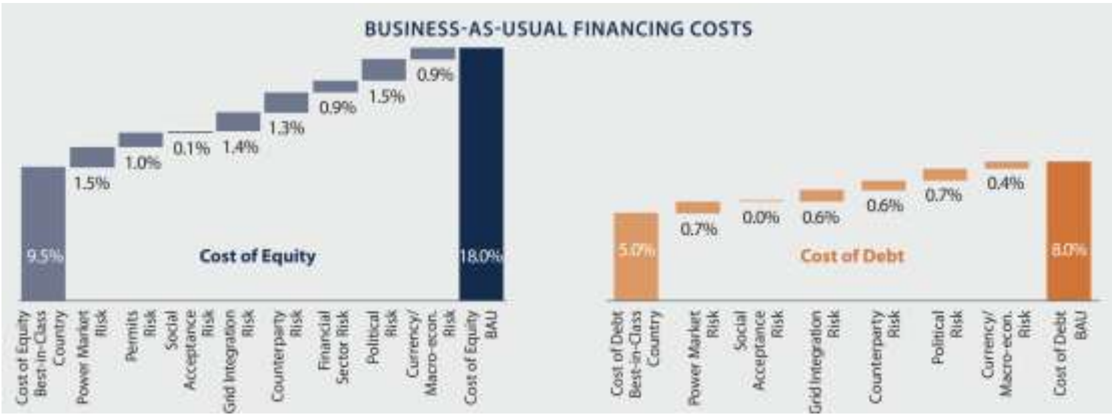
The case study identified four broad risk categories for Mongolia's wind sector, in line with the DREI framework but with their unique characteristics. Firstly, risks related to the policy and regulatory environment were driven by the absence of clear, long-term renewable energy policy and unpredictable feed-in tariffs. As a result, investors lacked confidence in power purchase agreements.

Secondly, risks associated with the financial sector or foreign exchange market including the limited capacity by local banks to finance long-term renewable energy projects. These projects would also present high exposure to currency mismatch due to the denomination of renewable energy equipment imports in US dollars, making the cost of capital uncompetitive with fossil-based options.

Thirdly, risks to infrastructure and commercial aspects included weak grid capacity, unstable dispatch systems, and absence of storage or balancing reserves. These challenges increased grid curtailment risks and uncertainty about power evacuation.

Finally, risks of a resource and technical nature included limited historical wind data, harsh winter icing conditions, and logistic constraints in transporting turbine components. As a result, there was high uncertainty in capacity factor estimates and maintenance costs. All these risks contributed to higher financing costs for wind energy projects in Mongolia, as shown in *Figure 31* (below) on the basis of the following investor perspectives on the main type of risks (overleaf):

Figure 31: Mongolia Wind Energy Financing Costs



Source: UNDP (2013)

- *Power Market Risk* – Investors appreciated the government's efforts to create an enabling regulatory environment (e.g., unbundling the energy sector, establishing an energy regulatory authority, introducing a FiT ranging from US$ 8-9.5 cents/kWh for regulated projects, phasing out of end-user subsidies). However, the absence of a long-term government roadmap for wind energy and limited utility experience created uncertainty (e.g., lengthy consultations, unclear processes for PPAs).
- *Political Risk* – Political instability, characterized by frequent coalition and cabinet changes in Mongolia, exerted a high impact on financing costs.
- *Grid Integration Risk* –Coal's dominance in Mongolia's energy mix and the transmission company's lack of wind energy experience were identified as significant barriers. These gaps affected grid stability due to outdated Soviet-era infrastructure, and the absence of a public grid code for wind, which hindered manufacturing players from optimizing turbine designs.
- *Counterparty Risk* –Mongolia's sovereign rating remained elevated, with banks often requiring government guarantees and letters of reassurance.
- *Permits Risk* – Investors associated this with administrative complexities, bureaucratic hurdles and corruption seen as obstacles key for developers.
- *Currency/Macro-Economic Risk* – Mongolia's strong economic performance was reassuring but high inflation and local currency-denominated PPAs introduced risks only manageable through financial hedging strategies.
- *Financial Sector Risk* – Mongolia's financial sector was underdeveloped, with limited capital and no prior experience in wind energy projects. Most financial actors were local or Chinese, with international awareness of wind energy potential in Mongolia remaining low. Development banks had in the past provided financial derisking products to bridge this gap.
- *Social Acceptance Risk* – Mongolia is sparsely populated and although identified wind sites occasionally affected herders, awareness-raising campaigns and stakeholder engagement mitigated these risks. This was alongside the Mongolian collective pride in adopting wind energy.

5.2.3 Mongolia Public Instruments

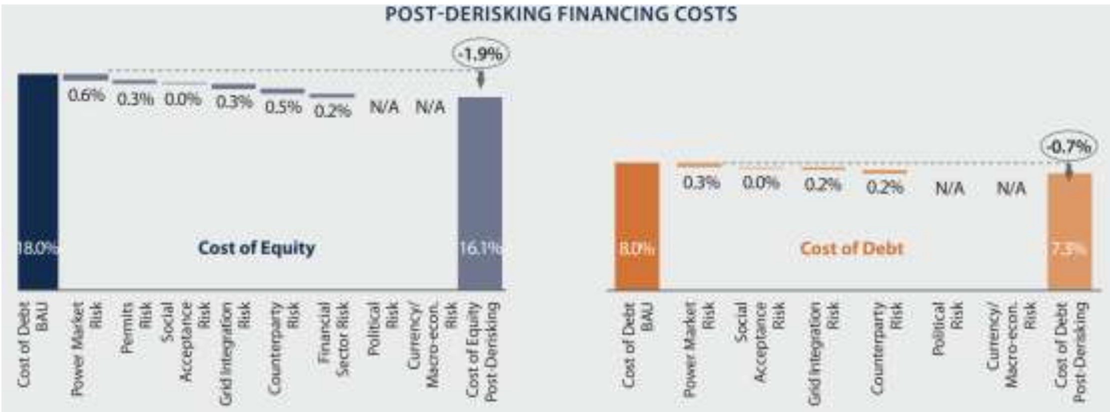
With regard to derisking measures to address these risks, Mongolia was classified as a non-investment-grade country. Therefore, the case study incorporated both financial and policy derisking instruments for a post-derisking scenario that would address some of the barriers to wind power deployment.

The financial derisking instruments included a combination of non-concessional public loans and commercial public loans with guarantees, alongside domestic-funded PPA price premiums. Additionally, Mongolia attracted international climate funds and investments from development finance institutions to co-finance and provide concessional lending.

Not only these instruments introduced new products, such as partial risk guarantees and blended finance mechanisms, but also help lower financing costs and enable the bankability of the Salkhit project.

Their projected impact on lowering the financing costs for wind energy in Mongolia is depicted in *Figure 32* (below), with an expected reduction of the average cost of equity and debt over a 20-year period by 1.9% and 0.7%:

Figure 32: Mongolia Wind Energy Policy Derisking



Source: UNDP (2013)

However, policy derisking instruments were also necessary to address the barriers driving up the above risks, which also needed removing or addressing in order to increase renewable energy investment.

For instance, Mongolia developed a Renewable Energy Law establishing feed-in-tariffs and guaranteed grid access; and introduced standardized PPAs to provide revenue predictability. The measures helped reduce the perceived regulatory uncertainty, which was a primary driver of higher weighted average cost of capital.

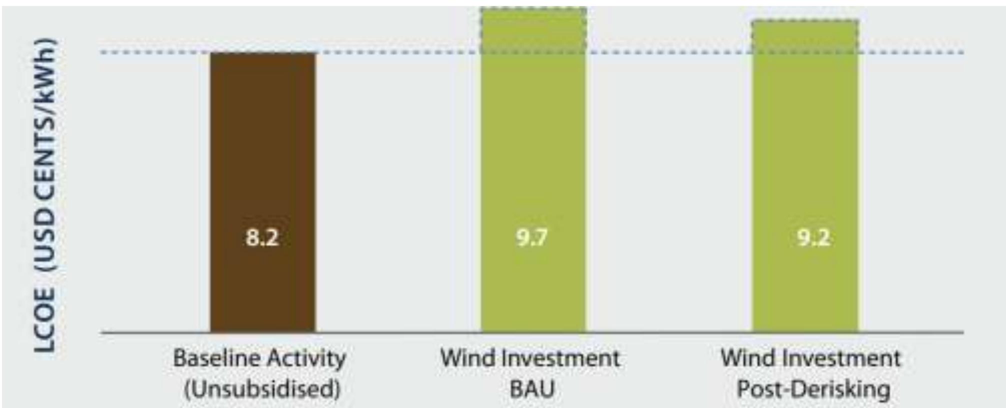
In addition, the grid integration studies undertaken and transmission upgrades carried out under Mongolia's National Renewable Energy Program facilitated the above policy developments. It informed the development of a grid code development tailored to intermittent sources, helped reduce investor perception of curtailment risk, and enhanced bankability of subsequent wind projects in Mongolia.

Finally, wind resource assessments and technical feasibility studies helped the introduction of standardized technical evaluation protocols for project approvals. These improved accuracy of project risk assessment, enabling lenders to refine financial models and reduce technical contingencies.

5.2.4 Mongolia Levelised Costs

The outputs of the DREI model application to the Mongolia case study in terms of Levelised Cost of Energy are presented in *Figure 33* (below); it showed that wind energy would remain more expensive than the unsubsidized marginal baseline (estimated LCOE at US$ 8.2 cents per kWh):

Figure 33: Mongolia Baseline Versus Wind LCOE



Source: UNDP (2013)

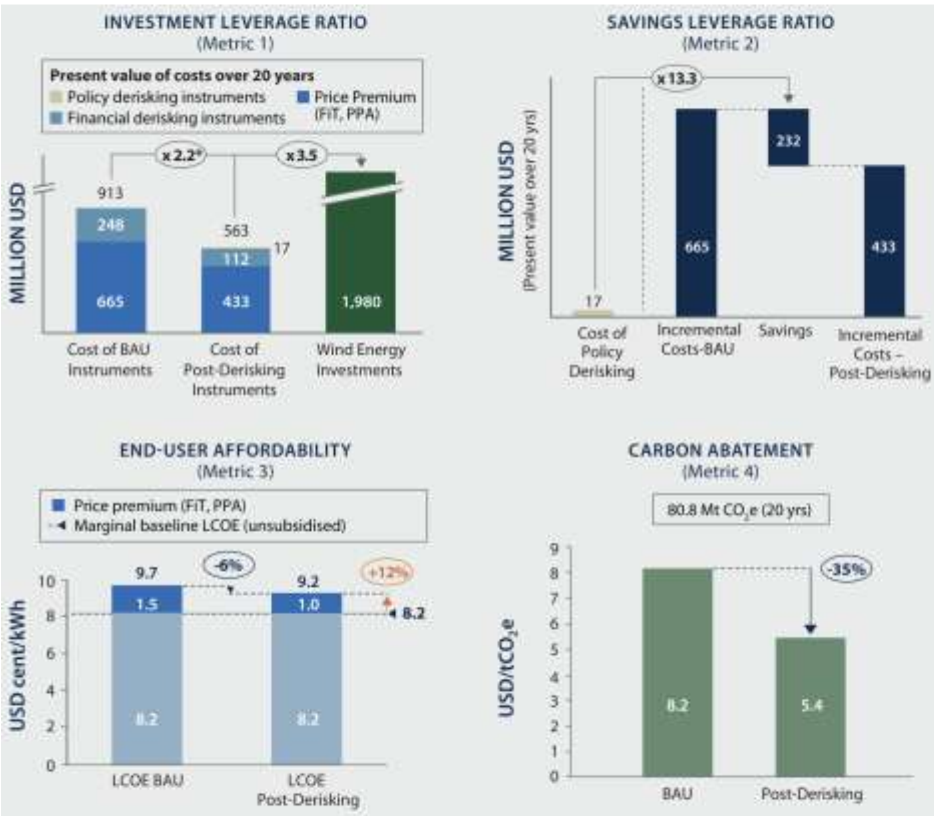
Policy derisking measures would reduce the LCOE for wind energy from US$ 9.7 cents per kWh in the business-as-usual (BAU) scenario to US$ 9.2 cents per kWh in the post-derisking scenario. However, the underscored financial incentives would be necessary to offset wind's incremental cost and make wind energy competitive. The Mongolian government FiT was capped at US$ 9.5 cents per kWh, and thus slightly below the BAU scenario LCOE of US$ 9.7 cents per kWh.

Overall, derisking instruments provided regulatory clarity and reduced revenue uncertainty, enabling long-term financial planning, which resulted in lower perceived political and offtake risk premiums; reduced the cost of debt and lengthened loan tenors, lowering the cost of capital; and, improved investor confidence in energy projections and long-term grid stability.

5.2.5 Mongolia Evaluation

The performance metrics of this DREI case study modelling impacts of derisking on a 1 GW wind energy investment target are shown in *Figure 34* (below):

Figure 34: Mongolian Wind Power Metrics



Source: UNDP (2013)

They highlighted the effectiveness of policy derisking to reduced need for incentives and financial derisking. The investment leverage ratio increased from 2.2x in the BAU scenario to 3.5x in the post-derisking scenario. With improved investment efficiency the estimated financial incentive required over 20 years would be reduced from US$ 665 million to US$ 433 million; the public cost of financial derisking would decrease from USD 248 million to USD 130 million. Additionally, the carbon abatement cost would drop by 35% to US$ 5.36 tCO_2e.

Mongolia's commissioning of the 50 MW Salkhit Wind Farm was the country's first grid-connected wind project. It demonstrated how derisking can attract private investment in a non-investment grade environment that was characterized by limited capital markets, institutional fragility, policy unpredictability and infrastructure constraints.

5.2.6 Mongolian Insights

A key take-away from the Mongolia case study is that non-investment grade status may not preclude renewable investment. As the main lesson for other countries, credible policy, predictable revenue, and de-risked finance are critical. The combination of stable feed-in tariffs, with blended finance and technical preparation, helped Mongolia convert high perceived risk into bankable opportunity. This approach is transferable to fragile economies, which can help shift renewables from donor-driven into commercially viable investments.

In effect, the main principles that can be drawn from this case study are investor preference of: (1) *predictability over subsidies*, such that a 15-20 year feed-in-tariff was more attractive than short-term incentive – therefore, well designed policies can offset sovereign creditworthiness by anchoring investor confidence to predictable regulatory environment; (2) *partnerships over grants*, with the use of concessional and guarantee instruments critical to crowd-in private capital instead of replacing it – hence, multilateral finance can play a catalytic role by absorbing the risk of first-loss; (3) *transparency over perfection*, where simple regulatory frameworks, when transparent and consistently applied, with reduced data uncertainty and increased institutional capacity can have a high impact.

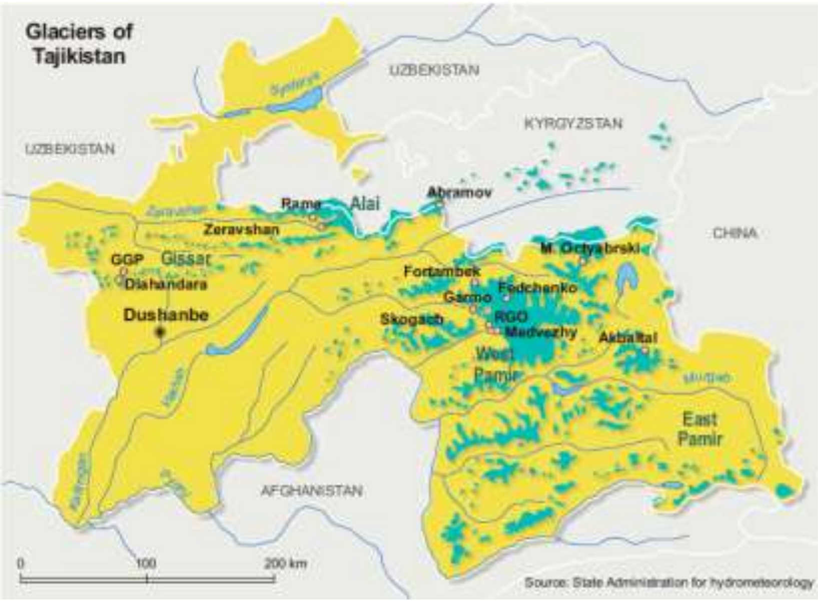
5.3 Tajikistan Resilient Hydropower

5.3.1 Tajikistan Overview

Tajikistan is the smallest country in Central Asia, spanning 143.1 thousand square kilometres across the region's mountainous terrain; it shares borders with Uzbekistan and Kyrgyzstan to the north and west, Afghanistan to the south, and China to the east, with approximately 70% of Tajikistan's population (8 million residing in rural areas (WB, 2021b). Despite its size, the country's importance is critical, as it serves as Central Asia's primary glacial hub (glaciers covering approximately 6% of its total land area).

These glaciers play a critical role in water retention, river flow regulation, and climate stabilization. They are also vital to the formation of the Amudarya River, the largest water artery for Central Asia and the Aral Sea Basin. Alongside permafrost, Tajikistan's glaciers are the primary sources of water replenishment for the Aral Sea river basins, with downstream countries heavily reliant on these water resources – see *Figure 35* (below). The rapid warming observed in Tajikistan's high-altitude regions is causing profound changes to glaciers, one of the country's most fragile ecosystems. It is also, key to hydropower development in the region, and was part of the author's field visit while at the World Bank.

Figure 35: Tajikistan Glaciers Map



Source: CIF (2023)

As identified by the author during field research, 70% of Tajikistan's population faced significant electricity shortages, meeting only about 75% of winter demand. The shortfall results in an estimated economic cost equivalent to 3% of the country's GDP, which Tajikistan sought to harness its vast hydropower potential for energy security and potential regional power exports (CIF, 2023).

Like with field research in Brazil and Paraguay, the visit underscored the importance of climate resilience considerations for the sector due to climate risks (98% of the country's electricity is generated from hydropower, with river basins dependent on glacial meltwater and snowmelt). Climate models predicted substantial changes in glacial dynamics, snowmelt, and precipitation patterns over coming decades, requiring hydropower infrastructure to be designed, rehabilitated, and managed to withstand frequent extreme events (e.g., floods, mudslides) while ensuring reliable, efficient electricity generation (WB, 2021b).

The World Bank engagement in Tajikistan's energy sector aligned with the government's strategy to ensure reliable power supply, address severe winter shortages, reduce system losses, strengthen financial management, and develop a framework for sustainable export of surplus summer electricity. However, the author was also overseeing the other economic, environmental, social, and water management considerations of this engagement, including necessary investments in productive landscapes and ecosystems for agriculture production.

From the NWHRM perspective, the inclusion of Tajikistan in the PhD thesis was underscored by the need to take an interdisciplinary approach to barriers of renewable energy deployment. Its process of sequential decision making from knowledge of potential to investment stages has so far proved relevant from a financial (economy), but also technical (energy) and environmental (ecology) standpoint – as become more apparent in Sub-Saharan Africa and Latin America. The application of the DREI model in Mongolia further uncovers implications for climate change mitigation and adaptation. The Tajikistan field visit, at the heart of Central Asia, also mirrored transboundary ecosystem restoration dimensions.

The expansion of the electricity grid was halted after the collapse of the Soviet Union, and the ensuing civil war in Tajikistan during the early 1990s. With inadequate maintenance and repair of power generation, transmission, and distribution systems, the electricity infrastructure suffered significant deterioration, particularly in rural areas the author visited outside of the capital city, Dushanbe, en route to the city of Khujand. Several areas had no electricity, while others experienced low-quality power plagued by frequent outages.

Rural residents, comprising over 70% of Tajikistan’s population, had moved to more remote locations and valleys in search of farmlands lacking grid access. Realising the country’s hydropower potential prioritized investment for large-scale projects like the Nurek and Sangtuda-1 670 MW hydroelectric plants, or the Rogun 3,400 MW power plant; however, these large facilities were primarily focused on exporting power and supporting industrial zones – thus, offering only a partial solution to rural energy needs (CIF, 2023). Over 95% of Tajikistan's electricity was generated by large hydropower plants, subject to strong seasonal production fluctuations (output lowest during winter, when demand does peak).

Additionally, the electricity grid was divided into northern and southern networks, both connected to the Central Asian network. This system fragmentation often caused inconsistent power supply in remote regions. The challenges were compounded by the poor condition of the power systems, characterized by voltage instability, frequent outages, inefficient dispatch systems, high transmission losses, and inadequate cost recovery. While most villages are technically connected to the grid, electricity supply during winter is limited to 2-6 hours per day, split between morning and evening. Summer power supply was more stable, yet some communities remained entirely off-grid.

Tajikistan’s fossil fuel resources were limited and underdeveloped. Although the country had large coal reserves in mountainous regions, development is hindered by poor road access and high extraction costs. As a result, the country relies heavily on imported fossil fuels, which undermines energy security. High import costs make fuel unaffordable for most rural households and public institutions.

Reliable energy access remained a critical development issue. Every winter, energy shortages result in rural areas receiving only a few hours of electricity per day. Liquefied petroleum gas (LPG) stoves and diesel generators are used by a small affluent minority in rural areas, but over 1 million people—primarily in rural regions—lack sufficient access to energy. Unreliable electricity hampers income-generating activities and has severe environmental consequences. To compensate for inadequate modern electricity, rural populations have turned to alternative local energy sources for cooking, lighting, and small-scale commercial activities. This has led to unsustainable deforestation, with high-value mountain forests being cut down. Studies show that in some areas, 70-80% of forest cover has been lost in the past 20 years, primarily due to energy demands (WB, 2021b).

Deforestation had caused soil erosion, natural resource degradation, and increased vulnerability to disasters like landslides during heavy rains. Additionally, inefficient cookstoves (10-30% efficiency rate) exacerbated the problem, while burning wood, dung, and coal in these stoves contributed to poor indoor air quality, posing serious health risks. The lack of heating in schools and hospitals further endangered vulnerable groups, especially in winter. The absence of a reliable energy supply also stifled opportunities to improve living conditions and develop income sources, such as agricultural processing.

This situation had the most severe consequences for Tajikistan's rural communities, among the poorest globally. Therefore, a reliable energy supply was crucial to alleviating poverty, and the government incorporated these issues into its national poverty reduction strategy. These included efforts to mitigate environmental damage and indirectly promote renewable energy solutions, such as sustainable fuelwood use, small-scale hydropower, biogas, and solar energy. The author's field visit included projects in the portfolio under its World Bank oversight, funded by the Climate Investment Funds' Pilot Program for Climate Resilience (CIF, 2023). Other projects were also under implementation, led by other development partners, such as the European Bank for Reconstruction and Development or the Asian Development Bank. However, the author's visits noted the need to take a portfolio approach to understand how these interventions could holistically, collectively address barriers to renewable energy investment.

5.3.2 Tajikistan Risk Environment

Tajikistan's Ministry of Energy and Industry oversees energy and industrial policies and acts as a lead partner in executing renewable energy projects. Barki Tojik, the state-owned enterprise responsible for electricity and thermal energy generation, transmission, and distribution, plays a critical role in implementing such state-funded projects. Per Resolution #267 from 1997, Barki Tojik is also required to purchase surplus energy from small hydro projects by private entities at established national tariffs. Other state level stakeholders included:

- *Committee for Environmental Protection*, responsible for environmental policy and key counterpart of the author's PPCR project portfolio.

- *Agency on Hydrometeorology* under the Committee for Environmental Protection, serving as the national focal point for the United Nations climate convention.

- *Ministries of Economic Development and Trade, and Labor and Social Protection*, which focus on poverty alleviation.

Tajikistan sought to rehabilitate the existing energy infrastructure to meet domestic and export needs, while introducing market reforms to attract local and foreign investments. This included improving financial health by enforcing payment compliance and increasing electricity tariffs to $0.02–$0.025 per kWh in the short term, and later to $0.05 per kWh (CIF, 2023). Emphasis was also placed on smaller scale renewable energy sources (RES), to drive development and poverty reduction goals. Policy regulations supporting RES investment included:

- *Comprehensive Target Program for Widespread Use of RES*, promoting small rivers, solar, wind, biomass, and geothermal energy.

- *Long-Term Program for Building Small Hydro Power Plants*, outlining plans for small hydropower development.

- *National Environmental Program* of the Republic of Tajikistan, emphasizing environmental sustainability.

Amendments to the 2007 Law on Energy mandated that utilities purchase electricity generated by small renewable energy plants at regulated prices. The 2010 Law on the Use of RES established a framework for promoting renewable energy to conserve non-renewable resources, reduce environmental impacts, and enhance energy efficiency (GEF, 2011). In addition, Tajikistan's First National Communication to the UNFCCC and subsequent technology needs assessment highlighted the country's small hydropower potential—estimated at over 18 billion kWh annually. With over 100 potential small-scale hydropower plant (SHP) sites identified, this assessment stressed the need for cost reduction through local production and improved technologies. Demonstrating SHP viability to local communities was critical to promoting their adoption.

Its Second National Communication to the UNFCCC emphasized that fully utilizing the SHP potential could reduce CO_2 emissions by 5–6 million tons annually, create local employment, and enhance rural energy access; however, Tajikistan faced high costs for fossil fuel imports and centralized heating systems due to its mountainous geography. SHPs, which cost around $1,100–$1,200 per kW to construct, were a cost-effective solution for remote areas; SHPs built during the Soviet era (69 plants of 32 MW capacity) were no longer operational due to poor maintenance, and lack of comprehensive planning (GEF, 2011).

Rural communities were eager to manage SHPs but lacked technical expertise and access to financing. There were also few companies capable of supporting SHP construction and maintenance due to an underdeveloped market. Without targeted interventions, key barriers—such as insufficient institutional support, inadequate technology, and limited financing—would continue to impede SHP development. Tajikistan was also implementing other strategies and programs related to natural resource management and sustainable land use. These included the National Framework Programme to Combat Desertification (2005) and the National Action Plan for Climate Change Mitigation (2003). The Government was also preparing its Third National Communication on Climate Change, to strengthen the evidence base regarding climate change risks and impacts on key sectors such as natural resources, and to facilitate the integration of climate adaptation and mitigation efforts into national development policies.

Despite these policy efforts the country faced several challenges behind the barriers to deployment identified on desk and field research. For instance, institutional and regulatory frameworks failed to effectively promote renewable energy or attract investments. This showed a lack of a holistic approach to stimulate both supply and demand for hydropower developments.

Tajikistan had complex administrative requirements and unclear licensing and inspection systems to enable business operations and burden consumers despite the fact that the new RES Law mandated procedure simplification. For instance, the 2010 RES Law lacked defined regulations for connecting small hydropower plants to the national grid, and implementation rules for preferential tariffs for producers. There was no tariff-setting methodology for RES electricity. The RES Law established a Renewable Energy and Energy Efficiency Fund for small hydro project support and electricity buy-back schemes that was not operational.

Additionally, the country had limited institutional capacity at central and local levels to enforce RES policies. Particularly it showed lack of capability to enforce the RES Law and related by-laws; lack of coordination among agencies in developing and enforcing RES policies; and insufficient technical information on SHP project development. Local manufacturers lacked SHP design knowledge, with technical and human capacities limitations reflected in the limited information on local SHP supply chains; technological and human resource constraints in SHP manufacturing; outdated technology in SHP design and construction; shortage of skilled technicians and designers for SHP projects.

Regarding limitations indirectly contributing to unsustainable land uses, Tajikistan had limited availability of energy-efficient heating and cooking devices, and low quality of locally produced appliances. Added to that, there was limited political and community support for SHP projects, lack of practical experience in their implementation and limited sustainability of such community-based projects. This was also driven by insufficient analysis to support national scaling-up programs, due to the low awareness among national decision-makers about SHP benefits, or absence of a national strategy for renewable energy-based rural development. This was also reflected in limited community development goals.

Beyond Tajikistan's borders, linked to transboundary aspects emanating from its glaciers, the country also faced outstanding disputes with the Kyrgyz Republic and Uzbekistan over access to water and energy resources. Part of the project interventions would need to trigger the application of World Bank environmental and social safeguard policies. This was due to the potential use of water from international waterways (Amu Darya river and tributaries), for any increased use of the amount of water abstracted, or the impact on hydrological regimes.

Climate change and variability would exacerbate these risks. Among countries in the Central Asia region, Tajikistan was considered the most vulnerable to the adverse effects of climate change. This was due to its heavy reliance on natural resources, like agriculture and hydropower, the insufficient climate resilience of key economic sectors, and its limited adaptive capacity to address ongoing and anticipated changes. Under conservative climate projections, Tajikistan was likely to experience rising temperatures, accelerated glacier melting, a higher frequency of flooding, and more severe and prolonged droughts (WB, 2021b).

These projected impacts jeopardized the country's poverty reduction efforts in achieving food and energy security. Over 90% of Tajikistan's 141,000 km^2 area consists of environmentally fragile mountain systems of regional and global importance. One-third of this land (4.6 million hectares) is designated as agricultural, with only 850,000 hectares classified as arable; the remaining area, including 2.5 million hectares in upland regions, is primarily used as permanent pasture. Agriculture and rangeland practices support the livelihoods of two-thirds of the population but are marked by low productivity.

Key threats to upland agro-ecosystems beyond the above climate risks include environmental impacts, such as severe soil erosion and loss of organic matter caused by unsustainable cropping practices, as well as rangeland degradation and deforestation from inefficient livestock and grazing management. Coupled with Tajikistan's climate vulnerability, the country had an untapped potential of sustainably managing mountain agro-ecosystems. Realising this potential would boost productivity, but also ensure the provision of essential ecosystem goods and services to both the country's population and the broader region (CIF, 2023).

In all, the main barriers to rural energy access were categorized into: (1) infrastructure and technical; (2) financial and economic; (3) institutional and governance; and, (4) social and geographic.

The main infrastructure and technical barriers included: (a) an *aging and inefficient grid infrastructure* – with rural transmission and distribution networks obsolete and poorly maintained, and unable to service remote off-grid locations in mountainous areas; (b) *seasonal and climate variability* – where heavy reliance on hydropower caused severe winter shortages when river inflows dropped and reservoir levels fell; with the mismatch between seasonal generation; (c) *limited decentralized generation capacity* – with only solar and micro-hydro grid pilots.

The financial and economic barriers included: (a) *tariff and revenue imbalances* – with electricity tariffs below cost-recovery levels, and chronic underinvestment and reliance on donor funding; (b) *limited access to rural electrification finance* – with local banks only offering short-term, high-interest loans; and lack of concessional financing mechanisms for rural households and small enterprises; (c) *dependence on foreign donor projects* – with most rural electrification initiatives financed by multilateral development banks and climate funds, with limited national budgetary support, and sustainability after project closure.

The institutional and governance barriers were associated to: (a) *centralized energy* concentrated in the capital city Dushanbe, and limited institutional coordination between ministries; (b) *lack of rural energy policy*, with the 2010 Renewable Energy Law (2010) lacking frameworks for rural electrification; (c) *limited human and technical capacity* for design, maintenance, and management.

Finally, social and geographic barriers included: (a) *mountainous and dispersed settlements* of over 70% of Tajikistan's population; (b) *energy poverty and limited affordability* of connection fees or equipment for off-grid systems, hence rural area reliance on traditional biomass, contributing to deforestation and health risks; and, (c) *limited awareness and acceptance of renewable energy technologies* with low public knowledge of the benefits of solar and micro-hydro power generation, and lack of trust in new systems due to past project failures.

5.3.3 Tajikistan Public Instruments

Tajikistan initiated the introduction of comprehensive strategies focused on regulatory reform, community engagement, and capacity building to ensure the sustainable development of both small-scale hydropower and other rural livelihood sectors (CIF, 2023). Their goal was to improve and expand legislative and regulatory framework for such developments throughout the country.

These included regulations to adopt, enforce and operationalize the RES Law through streamlined procedures for licensing and construction of hydropower facilities; a national cadastre to facilitate monitoring; technical regulations for SHP grid integration, including technical conditions for their connection; monitoring systems to verify electricity production and ensure compliance with tariff guarantees. Derisking measures included the operationalization of the fund to support community-based projects; development of a standard methodology for financial evaluation of small hydro projects, tariff setting, and a PPA template.

In addition, Tajikistan started strengthening the institutional capacity at central and local levels to implement and coordinate these policies. Examples included training programs for government officials on RES policy development and execution; strengthening the Inter-Ministerial Task Force to coordinate policies, monitor progress, and report to the Parliament and President; enhancing the technical expertise and market development for small hydro projects; guidebooks on the technical and policy aspects of SHP deployment, alongside others summarizing regulations, methods, and standardized SHP designs.

The focus extended to equipping local SHP manufacturers to provide turn-key solutions and operation and maintenance services. These activities included the selection of manufacturers competitively and development of capacity enhancement plans; conducting on-the-job capacity-building programs, including joint SHP design, construction, and quality assurance for pilot projects; upgrading technological bases of manufacturers with cost-sharing support; vocational training programs for SHP professionals; and, building manufacturers' capacity through joint product design, assembly, and marketing efforts.

Complementing these interventions, Tajikistan put emphasis on proving the technical and economic viability of small hydropower and other rural developments. These included studies and frameworks to support pilot projects; updating hydrological data, feasibility studies, and integration into rural and district development plans, to raise community awareness, and build local project planning and management capacities. These interventions were part of the government's Strategic Program for Climate Resilience (SPCR), supported by multilateral development banks (MDBs) projects, such as the Environmental Land Management and Rural Livelihoods (ELMARL) alongside the below totaling US$50 million of CIF-funded derisking interventions (CIF, 2023):

- *Enhancing Climate Resilience of the Energy Sector* (US$10m)

- *Climate Science and Modelling Program* (US$3m)

- *Improvement of Weather, Climate, and Hydrological Service Delivery* (US$7m)

- *Building Climate Resilience in the Pyanj River Basin* ($15.3m)

- *Building Capacity for Climate Resilience* ($3m).

Finally, these programmatic interventions were also set to foster the adoption of sustainable land management practices, alongside small-scale infrastructure investments that would enhance the climate resilience of rural livelihoods. They stressed community adaptation to meet joint environmental, economic and social goals, including: (a) *farm production*, to enhance crop productivity and diversification, livestock improvements and agro-processing; (b) *land resource management*, including pasture, water and soil fertility enhancements, integrated pest management, and sustainable cultivation; (c) *small-scale rural infrastructure*, rehabilitating irrigation and drainage systems, improving minor transport infrastructure, and promoting renewable energy and energy efficiency. Analytical studies would address soil quality, land degradation, market development and incentive policies for sustainable practices. Dissemination of best practices, tools and approaches would also promote replication and sustainability of efforts through knowledge exchanges at the farm, regional and national levels.

5.3.4 Tajikistan Levelised Costs

In the post-derisking scenario where the above interventions would have a meaningful impact in addressing barriers to renewable energy deployment, Tajikistan would have by 2025 a population of 4,000,000 with insufficient access to grid power for basic energy needs (lighting, cooking, heating) benefitting from small scale hydropower development. This would contrast with the 5,000,000 population projected in a business as usual (BAU) scenario. While the annual consumption of fuel wood would remain at $1m^3$ per capita in either scenario, the total estimated consumption of fuel wood would drop from 5,000,000 to 4,000,000 m^3, with the consequent reduction of emissions from fuel wood consumption to 6,280,000 tCO2, from the projected 7,850,000 tCO2 (GEF, 2011).

For instance, by the end of derisking interventions, around 10 small hydropower SHP plants were expected to be operational, with an additional 17 in advanced stages of preparation; together, these were projected to achieve direct CO2 emission reductions of 244 kilotons (ktCO2) over the 20-year lifespan of an SHP, including direct and post-project emission reductions. Indirect emission reductions, as a long-term impact of the project, were estimated to range from 733,000 tCO2 to 2.48 million tCO2 (ibid.). The unit abatement cost, based on expected direct and post-project direct CO2 reductions, was calculated at US$8.19/ton CO2, considered cost-effective compared to then prevailing carbon market prices (approximately €10-14/tCO2).

These findings aligned with the Tajikistan National Communication to the UNFCCC and Technology Needs Assessment, which identified SHP investment as the least costly option for reducing GHG emissions, compared to alternatives such as other renewable energy sources (solar, wind) or industrial sector mitigation measures (cement, aluminium, and chemical industries). In a pre-derisking scenario, only limited, scattered, and largely uncoordinated small scale rural infrastructure activities would take place, and lead to an unnecessary wastage of scarce financial resources, plus default to siloed support from bilateral and multilateral donor agencies whose activities would have remained limited in scope.

5.3.5 Tajikistan Evaluation

The policy derisking interventions in Tajikistan addressed barriers to both energy deployments and environmental developments associated with climate change mitigation and adaptation, landscape and ecosystem restoration. On the energy front, the field mission did not witness the development of small hydropower plants, which came afterwards, yet saw progress on the design of financial support mechanisms for renewable energy and energy efficiency.

Big part of the challenge for the country has been its focus on large-scale hydropower projects, such as the 3,600 MW Rogun hydropower plant; but Tajikistan's Ministry of Energy and Water Resources revised and adopted national strategies to enable the development of smaller scale investments in promising sites (CIF, 2023). These led to development of legislative and regulatory framework for SHP development, EE and RE legislation and strengthening the ministry's capacity to assess SHP feasibility and sustainability.

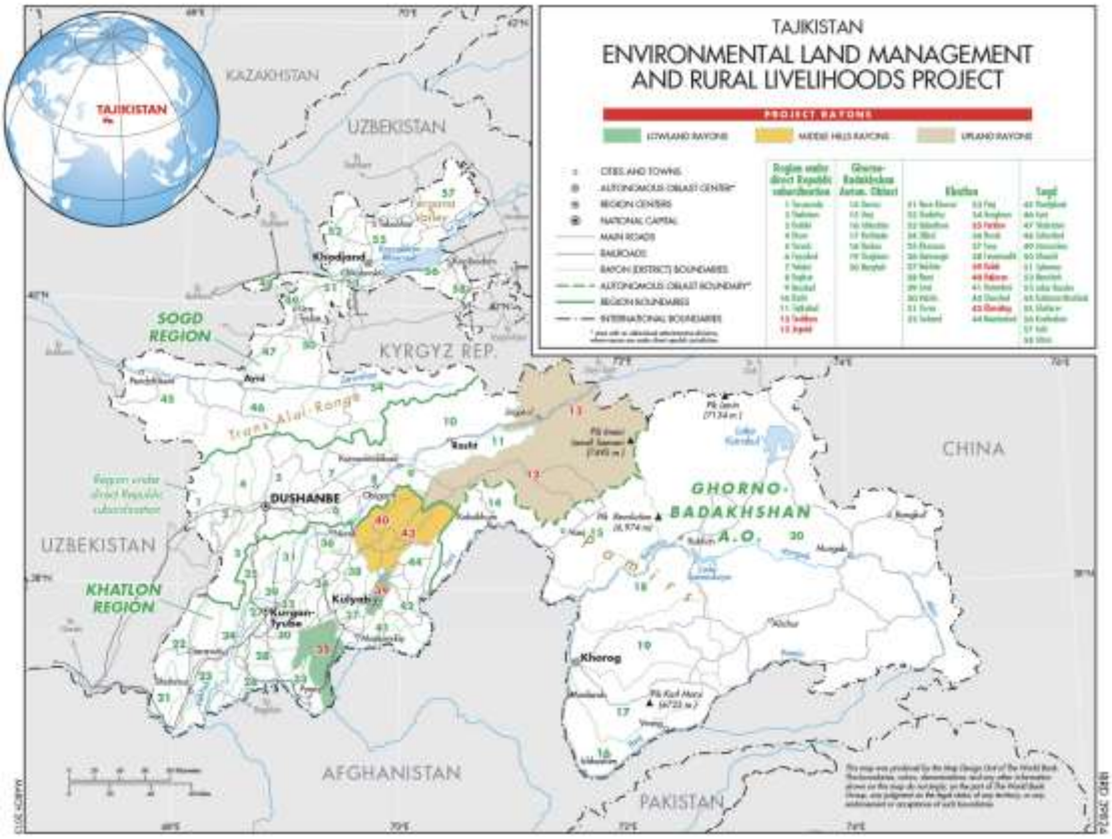
The implementation of technology transfer initiatives, including training of local production companies for small hydro project technology manufacturing supported the production of SHP components, with a share of the value chain reaching 60% local content for new plants under construction. In the process, vocational training and dissemination activities helped cement that diffusion. In parallel, feasibility studies were conducted for potential sites that were incorporated into a national small hydropower.

Some lessons learned from these developments include the need for subsidies to overcome the limitations of private investment and market mechanisms in countries such as Tajikistan. The public finance envisaged under their energy efficiency and renewable energy Trust Fund did not materialize. However, encouraging small scale project developments show the potential for exporting electricity, as an offset to the cost of new power generation projects, reduction of domestic electricity prices, and subsidy requirements. Developments of this scale should target off-grid locations, where the impact on livelihoods is greatest. Such efforts would further contribute to increase energy access and climate resilience.

On the environmental front, policy derisking interventions increased the productive assets of rural populations through direct grant financing for sub-projects. The sub-projects aimed at improving five key dimensions of well-being: social, human, financial, physical, and natural capital reaching more than 300,000 direct beneficiaries, with women comprising 48% of them (WB, 2018):

- **Social Capital** – Community-based development approaches contributed to the strengthening of social cohesion and cooperation in rural Tajikistan. These included the formation of over 2,000 Common Interest Groups (CIGs), eight Pasture User Unions (PUUs), support to 16 existing Water User Associations (WUAs), and a common sense of purpose.
- **Human Capital** – The delivery of more than 35,000 client days of training on technical and non-technical topics, more than 350 types of training and communication materials, including a knowledge management platform to share climate learnings, led to an uptake by the community of key skills, improvements in water access, food production and living conditions.
- **Natural Capital** – Natural resource management practices tailored to local agro-ecological conditions led to the reduction of soil erosion, increase of vegetative cover, improvement of soil quality and moisture conservation, optimization of water use efficiency, and promotion of renewable energy use. Over 53,000 rural households spread over Tajikistan's climate vulnerable regions of Tavildara/Sangvor, Jirgatol/Lakhsh, Baljuvon, Hovaling, Kulob, and Farkhor (*Figure 36* below) adopted climate-resilient, nature-based practices.
- **Physical Capital** – Rural infrastructure and sustainable land management improvements enhanced productivity and resource use efficiency through the reparation of irrigation systems, rehabilitation of roads, installation of water meters, and adoption of drip irrigation.
- **Financial Capital** – The allocation of US$11.3million in investments for rural production and land resource management, based on well-being assessments, showed that 53% of participating rural households improved their well-being by an average of 25%, compared to 46% for non-participating households; participants maintained purchasing power during economic shocks, increases in employment generation and women's well-being compared to men.

Figure 36: Tajikistan Project ELMARL



Source: WB (2018)

The combined renewable energy and sustainable land management measures helped improve the climate resilience of rural productive livelihoods, with relevant gender, health, jobs and overall community well-being outcomes. The outcomes were the result of Tajikistan's SPCR's programmatic approach that guided individually MDB-implemented PPCR-funded interventions collectively addressing barriers to deployment of renewable energy – see *Table 20* (below), which were underpinned by technical assistance on the country's institutional arrangements, climate science and modelling analyses and awareness raising:

Table 20: Tajikistan Pilot Program for Climate Resilience

Name	PPCR Funding (USD million)	Co-Financing (USD million)	MDB
Building Capacity for Climate Resilience	6	0	ADB
Building Climate Resilience in the Pyanj River Basin Project	21.55	1	ADB
Enhancing the Climate Resilience of the Energy Sector	11	54	EBRD
Enhancing the Climate Resilience of the Energy Sector	10		EBRD
Environmental Land Management and Rural Livelihoods – AF	2	2	IBRD
Environmental Land Management and Rural Livelihoods Project	9.45	7	IBRD
Improvement of Weather, Climate, and Hydrological Delivery Project	7	15	IBRD
Small Business Climate Resilience Financing Facility	5	8	EBRD

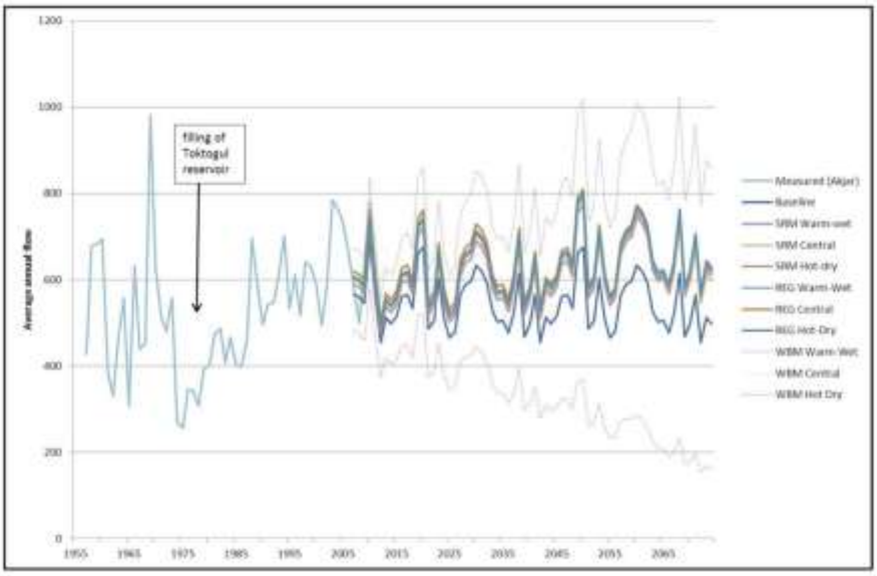
Source: WB (2018)

The cost-benefit analysis of the ELMARL project alone shows quantifiable benefits in agricultural productivity improvements not only from on-farm production, pasture, water management, but also cost savings from rural infrastructure, renewable energy and transport included. The project was set to achieve a net present value (NPV) of $28 million by its sixth year, and a financial internal rate of return (IRR) of 56% with additional financing (WB, 2018). The analysis showed additional climate change mitigation and adaptation benefits.

On the mitigation front, the ELMARL alongside other PPCR Tajikistan derisking interventions listed in *Table 20* (above), also contributed to the reduction of emissions through carbon sequestration. Using the FAO Ex-Ante Carbon-balance Tool (EX-ACT) methodology (FAO, 2022), the project implementation between 2014 and 2017 of over 2,300 local sub-projects across 9,439 ha., 134 WUAs projects transforming 22,544 ha. and 158 PUUs projects transforming 11,747 ha. resulted in 43,675 ha. contributing to carbon stock restoration and enhancement. The carbon balance over 20 years was set to be negative or a carbon sink of -262,490.58 tCO2-e from local sub-projects, -713,907.12 tCO2-e from both PUU and WUA activities (PUU: -210,615.32 tCO2-e, WUA: -503,354.80 tCO2-e. Based on EX-ACT analysis and World Bank shadow carbon price guidance (WB, 2024), using a 12% discount rate over 20 years, the NPV of greenhouse gas mitigation estimated at the project completion would be US$4 million with a low shadow price of US$34/tCO2-e, or US$8 million with a shadow price of US$78/tCO2-e.

On the adaptation front, the benefits resulted from the programmatic integration of the ELMARL and other Tajikistan PPCR-supported projects. The portfolio of derisking interventions include the "Improvement of Weather, Climate and Hydrological Delivery Project" under the author's World Bank oversight, and the "Enhancing the Climate Resilience of the Energy Sector" implemented by EBRD. They collectively contributed to adoption of international best practices in managing climate risks of hydropower operations and hydrometeorological services and the strengthening of institutional capacities for effective transboundary management. These would lead to the integration of climate resilience standards and technologies and modernization of hydropower facilities to secure electricity supply in different scenarios–see *Figure 37* (below):

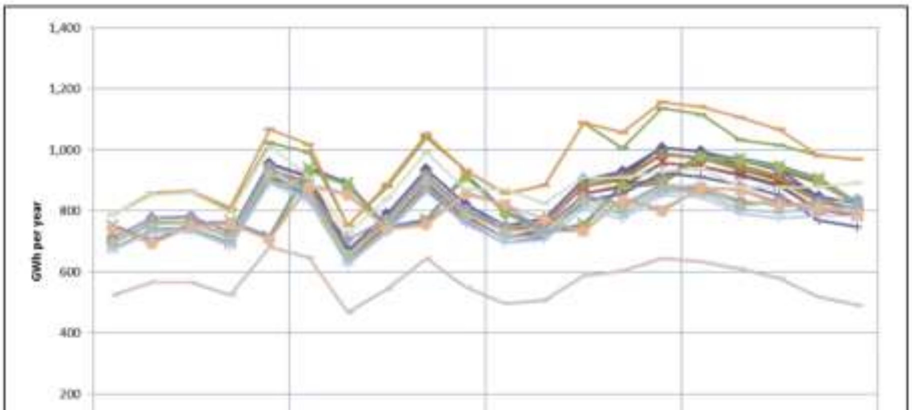
Figure 37: Kairakkum Reservoir Climate Scenarios



Source: CIF (2023)

The PPCR Tajikistan derisking interventions included measurement and modelling of the inflows of the Syr Darya River into the Kairakkum reservoir of the northern part of the country bordering the Kyrgyz Republic. They helped inform hydrological scenarios and optimal designs of potential Kairakkum hydropower plant upgrades, such as selection of technologies and turbine capacity. These scenarios would be then used to simulate energy production under different turbine upgrade options – see *Figure 38* (below), to see which one would demonstrate the best performance across projected climate and hydrological conditions, including probable maximum flood for the reservoir:

Figure 38: Kairakkum Hydropower Plant Generation Scenarios



Source: CIF (2023)

The Kairakkum hydropower plant was constructed in 1959 and served both as seasonal regulation for irrigation and electricity generation. Most of the plant's electrical and mechanical equipment surpassed its operational lifespan, with turbine replacement amongst other required upgrades. Refurbished turbines would also be key to optimize energy generation amidst hydrological variability exacerbated by climate change., beyond the need to address energy deficits. Such derisking intervention served as one of the case studies and lessons learned for the hydropower climate resilience guidelines that the author also contributed to. These were also disseminated during the research period at international fora.

5.3.6 Tajikistan Insights

The barriers to rural energy access in Tajikistan ultimately were not about lack of resources, but about systemic constraints associated to aging infrastructure, weak institutions, and financial unviability. One key lesson for energy policy is that derisking rural electrification requires not only technical investment but also institutional reform, targeted subsidies, and decentralized governance mechanisms. It is also aligned with the main thesis argument that energy access depends on integrating financial, regulatory, and social derisking measures.

The Tajikistan case in Central Asia underscores that climate change impacts all human, natural and physical systems worldwide posing a threat to sustainable development. Just like the Paraguay case showed in Latin America, these impacts also put at risk renewable energy sources, especially water for hydropower purposes, and its surrounding ecosystems (watersheds, landscapes, forests). These case studies show how complex is to predict how these impacts might manifest, or what trend they will follow, but they are likely to be non-linear and highly unpredictable, particularly as the world reaches climate tipping points. While focus is often placed on the planet, climate risks also disproportionately manifest on people, particularly poor, elder, young and other vulnerable populations, with women and girls further at risk due to pre-existing conditions. These include traditional local communities and indigenous peoples, who are highly reliant on the natural resources for their subsistence.

With hydropower still representing a large share of renewable energy installed capacity worldwide and annually producing a significant part of total renewable energy generation, it is clear that it also plays a big part in the achievement of the mid-century climate mitigation targets included in the Paris Climate Agreement. It is thus critical for the attainment of the 2030 Sustainable Development Goals. Yet, while hydropower will also be affected by the climate shocks, there is comparatively lesser attention placed on its climate adaptation and resilience considerations. It offers protection against these shocks, including floods and drought, but ultimately hydropower is also vulnerable to climate risks given its dependency on precipitation, surface runoff and other water flow factors.

As in the case of Paraguay, Tajikistan is among the most hydropower-dependent countries in the world, with over 95% of its electricity is generated from plants, notably along the Vakhsh and Panj river basins. Its importance for the national economy, providing electricity, export revenue (via potential trade with Uzbekistan and Afghanistan) and employment, also makes its energy system highly exposed to climate variability and long-term hydrological change. Thus, climate resilience is not just an environmental concern, as it also affects macroeconomic stability, energy security, poverty and social inclusion.

The similarities include direct translation of seasonal hydrological fluctuations into potential electricity shortage. It requires climate-resilient hydropower operations and maintenance to stabilize year-round supply, and multi-reservoir coordination, with improved forecasting. Climate change adaptation is critical to build resilience to future revenue generation, domestic energy supply and export reliability. In the absence of derisking, the first to experience load shedding during dry years are rural areas, with the impact on their health and livelihoods.

Key solution emerging from the case study is the need to integrate climate resilience into hydropower planning, including: (1) *technical resilience*, by climate-proofing dam design, hydrological modelling and adaptation operation; (2) *institutional resilience*, as climate risk assessment becomes part of energy planning, environmental impact assessment, or power purchase agreements; (3) *financial resilience*, as climate risk instruments help shift investors exposure.

6 Evaluation of Barriers in Caribbean Countries Applying the Derisking Renewable Energy Investment Model

6.1 Caribbean Context

The DREI framework was introduced in 2013 with the release of the initial DREI report (UNDP, 2013). While the author contributed to it while overseeing the Latin America and Caribbean (LAC) UNDP-GEF climate change mitigation portfolio, the framework was not applied to the Caribbean region in theory. In practice, the DREI model guided several project developments listed in the *Table 21* (below). The author undertook several field visits from his Panama base, also complemented by his relocation to the US; thus, the Caribbean case studies also draw on the author's technical and advisory expertise in energy, infrastructure, transport and technology (covering mostly Mexico, Central America and the Caribbean), and managerial experience overseeing the World Bank environment, natural resources and climate resilience portfolio, covering the entire LAC region.

Table 21: Caribbean Derisking Instruments

Type	Funding Source		Renewable Energy Source		
			Hydro	Solar	Other/Misc.
Grant	Multi-lateral	Global Environment Facility	- *UNDP* Haiti Small Scale Hydro Project - *UNDP* St. Vincent & Grenadines PACES Project	- *UNDP* Regional-Derisking Ten Island Challenge - *UNDP* Jamaica RE & EE Deployment - *UNDP* St Vincent & Grenadines PACES Project - *UNDP* Barbados DREAM Project	- *UNDP* Dominica Low Carbon Development Path - *UNDP* Cuba Clean Energy - *UNDP* Caribbean Renewable Energy Development Programme
		Climate Investment Funds	- *WB* Haiti Pilot Program for Climate Resilience - *WB* Haiti Scale-up Renewable Energy Program	- *WB* Haiti Scale-up Renewable Energy Program - *IFC* Haiti Scale-up Renewable Energy Program - *IDA* Haiti Scale-up Renewable Energy Program	- *WB* Jamaica Pilot Program for Climate Resilience - *WB* St. Lucia Disaster Vulnerability Reduction Project
	Bilateral	Japan	- *UNDP* Japan-Caribbean Climate Change Project		

Source: Author's desk, field research compilation and contribution

Part of the focus of the application of the DREI model is in the diverse Eastern Caribbean, but also draw on the author's desk and field research in Haiti and Jamaica. Most findings reflect lessons from the mobilization of technical assistance, advisory services, investment project financing and other derisking instruments (development policy loans, credits and guarantees, carbon finance).

In four years (2011-2015) residing in Panama City, and another four years (2015-2019) in Washington, DC the author undertook field missions and site visits to all independent countries across the Caribbean. Like in Latin America, the engagements included advisory services, knowledge dissemination and climate finance mobilization to address barriers of sustainable energy, resilient infrastructure and both blue and green economy interventions relevant to SIDS. The Caribbean was heavily reliant on imported fossil fuels, with petroleum products comprising approximately 93% of commercial energy consumption, including conventional electricity generation for power plants (GEF, 2013c).

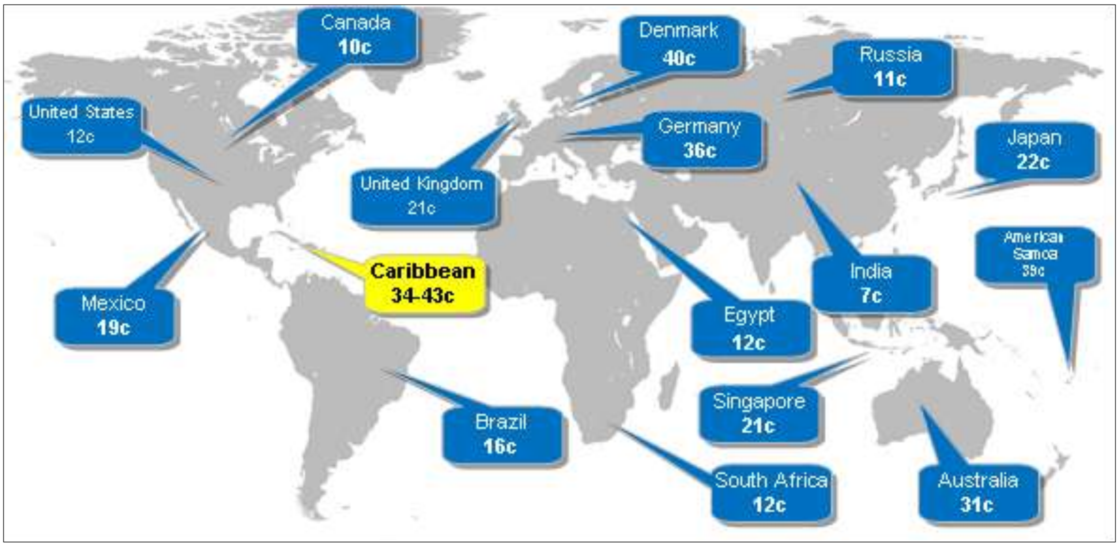
This dependency is a major contributor to the region's greenhouse gas emissions footprint, and despite its abundant renewable energy potential, its utilization remains significantly underdeveloped, while expanding electricity generation is a critical component of economic development for its countries. They remain particularly vulnerable to fluctuations in global oil prices, with larger portions of national budgets to be allocated to fuel imports, which strain their foreign currency reserves, balance of payments, and funds for essential services (e.g., health, education, and national security). Ensuring energy security in terms of affordability and reliability also remains a pressing concern, with extenuating factors such as the geographic isolation of islands, small market sizes and the lack of inter-island electrical grid connections – see *Figure 39* (below):

Figure 39: The Caribbean Region

Source: GEF (2013c)

The regions reliance on inefficient diesel-powered electricity generation contributed to some of the highest electricity tariffs globally– see global vis-à-vis Caribbean electricity price comparisons in *Figure 40* (below); it made the region vulnerable to its market fluctuations with resulting negative economic impacts, while the region's renewable energy resources—wind, solar and geothermal remained largely underutilized. Renewable energy investments required a more conducive policy and financial environment in SIDS than in OECD economies. With derisking renewable energy can be cost-competitive with conventional power at prices that reach US$0.50/kWh across the Caribbean (GEF, 2015):

Figure 40: Global-Caribbean Electricity Price Comparisons



Source: GEF (2015)

Saint Lucia, for instance, imported nearly all the oil required to operate its single power plant, and according to the Caribbean Electricity Service Corporation (CARILEC), electricity prices averaged at least US$0.34/kWh, against an average annual household income of US$12,800 that makes this dependence on imported fossil fuels both a climate and economic issue further underscoring its importance. It contrasted with its robust renewable energy potential, with solar irradiance consistent throughout the year due to minimal seasonal daylight variation, strong and reliable wind speeds and untapped potential for bioenergy, hydropower and geothermal energy. Despite these compelling reasons, island nations across the region have not realized the potential behind the transition from fossil fuels to renewable energy, nor created the market for investment.

With energy vital to all sectors of the Caribbean economy, many Caribbean Community (CARICOM) member states started taking steps to foster the development of local energy resources, expand the use of renewable energy, and promote energy efficiency and conservation. Countries endowed with renewable energy sources such as wind, solar, hydro, geothermal, and biofuels were increasingly prioritizing their development. For instance, Barbados, Commonwealth of Dominica, Haiti, Jamaica or Saint Vincent and the Grenadines, started adopting national energy policies aimed at harnessing renewable resources and improving energy efficiency, with noteworthy successes (e.g., solar water heating in Barbados, wind and hydropower projects in Jamaica). However, the overall replication across the region has been limited. In the meantime, the Caribbean largely composed of SIDS has been strong advocates for climate action.

The author's witnessed such positioning at its first ever participation at a climate conference in 2009. This was ahead of the much awaited but deemed disappointing "Copenhagen Accord" coming out of the 15th Conference of the Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC) in Denmark. While outside of the PhD thesis research period, this event shaped the author's perception about the importance of these conferences to assess the barriers to renewable energy deployment. As the author then codified (Alfaro-Pelico, 2010 and 2012), the COP15 and successive summits highlighted the impacts, policies and stance of LDCs, such as Haiti, as well as SIDS like Barbados, the Commonwealth of Dominica, Jamaica and Saint Vincent and the Grenadines, on key climate negotiation areas of mitigation, adaptation, technology and finance to be translated into renewables investment.

Most of these action areas aligned with the priority objectives outlined by SIDS in the Barbados Programme of Action for the Sustainable Development of Small Island Developing States (BPoA), originally adopted in 1994 in Bridgetown; these were further strengthened a decade later through the Mauritius Strategy for its Enhanced Implementation (BPoA+10 or MSI). For instance, on mitigation, at the time the primary contributors to global emissions were major sectors directly linked to achieving the then Millennium Development Goals (MDGs).

These included electricity and heat generation (29%), agriculture (14%), and land-use change and forestry (12%) (Alfaro-Pelico, 2010). That said, SIDS cited their minimal greenhouse gas emissions—then estimated at less than 0.05% of global emissions—as a key reason for not prioritizing mitigation (Alfaro-Pelico, 2012). SIDS dependence on costly transportation fuels became a catalyst for transforming inefficient, fossil-fuel-reliant industries into low-carbon economic sectors. They were estimated to consume over 220 million barrels of petroleum annually to meet their energy needs; and, with exceptions like oil-producing Guyana, Suriname and Trinidad and Tobago, 90% of their commercial and industrial energy demand depends on imported fossil fuels—in some cases, electricity costs are as much as 500% higher than in the USA (ibid.). Therefore, there was growing recognition in the Caribbean that diversifying the energy mix with greater reliance on renewable resources could lead to fuel import savings.

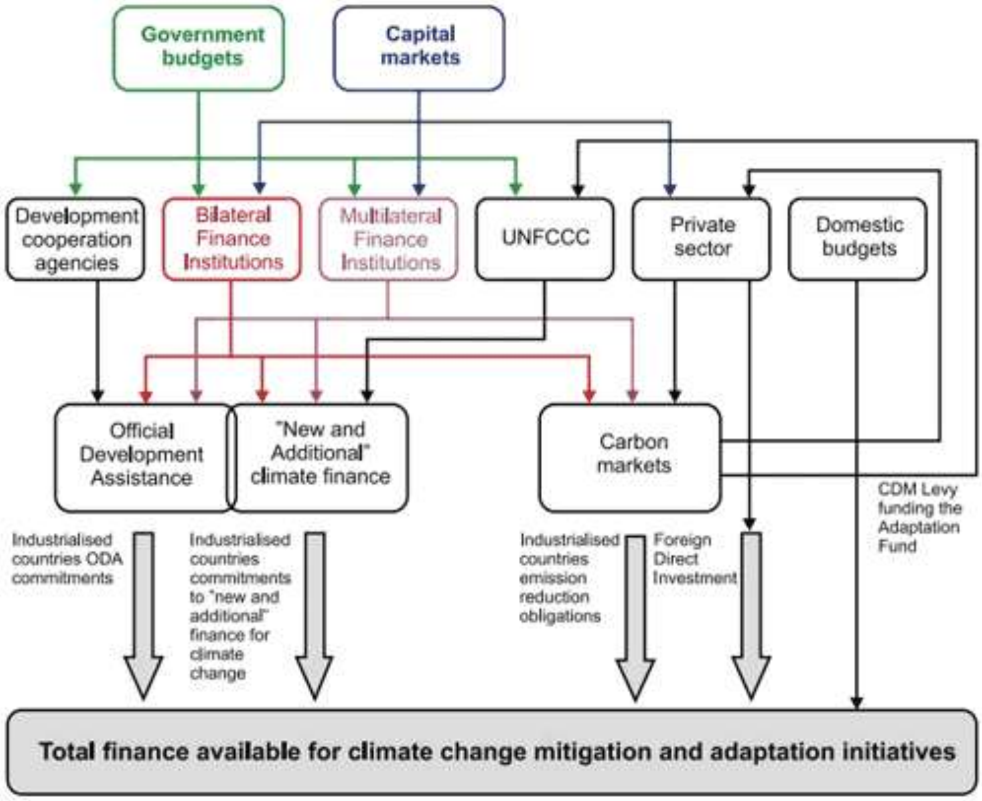
On adaptation, the key goal was to enhance climate resilience, particularly in the context of current development assistance, to bolster the ability of national institutions to integrate adaptive planning and management into development policies through an iterative process, with emphasis on proactive actions. Tackling heightened vulnerability and addressing climate-related threats are core priorities in the SIDS policy toolbox, aligned with the BPoA and the MSI, with targeted action on sea-level rise, disaster risks and water management.

On technology, for LDCs and SIDS to effectively pursue climate change mitigation while advancing economic development, transfer, diffusion and capacity building would need to be efficiently implemented, which demanded substantial investment alongside capacity development and technical support to drive economic transformation and achieve energy-related poverty reduction benefits.

Yet, the major obstacle to transform the economies of these vulnerable countries toward pursuing low-carbon and climate-resilient development paths is securing sustainable financing. This challenge spanned institutional, regulatory, and policy development levels, all of which are essential to attract investment. This is how the author identified the importance and unpredictability of international climate funding.

The fast-start finance pledged at the COP15 Copenhagen climate talks—i.e., $30 billion for 2010-2012, and the $100 billion per year projected from 2020—offered no clarity on allocation methods or eligibility criteria (Alfaro-Pelico, 2010). It was a key milestone for the author's learning and future derisking of renewable energy investments, by supporting SIDS and LDCs on how to access climate finance mechanisms in a complex web – see *Figure 41* (below):

Figure 41: 2012 Climate Finance Architecture



Source: Alfaro-Pelico (2012)

Further to the UNFCCC COP16 Cancun Agreements of Mexico in 2010, developing countries across the Caribbean undertook nationally appropriate mitigation actions (NAMAs) within the framework of sustainable development. These actions, supported by technology, financing, and capacity-building, aimed to achieve a reduction in emissions compared to "business as usual" levels by 2020. At COP17 in Durban, the UNFCCC also adopted a decision on National Adaptation Plans (NAPs), which then gained traction in the Caribbean also with GEF support. Yet SIDS faced, and still do today, significant challenges in accessing and managing climate funds to cover their adaptation and mitigation expenses.

These funds offer an alternative source of financing to safeguard development efforts against recurring disasters, limited national budgets, and declining development aid, particularly in the context of a global financial crisis. However, this created a dual dilemma. First, the availability of financing within the multilateral climate framework is not equally accessible to all countries. Second, climate funds provided through mechanisms under the UNFCCC—such as the Global Environment Facility (GEF) and the Adaptation Fund (AF)—are insufficient to fully cover their climate-related costs. Therefore, these funds needed to be strategically combined and sequenced to unlock access to other financing sources and managed to ensure their impact (Alfaro-Pelico, 2012).

The 2012 "Barbados Declaration" outlined 22 voluntary commitments from SIDS to contribute to the Sustainable Energy for All (SE4ALL) initiative, reaffirmed at the Rio+20 UNCSD Conference. Many of these commitments drove the author's advice, design, support and project conceptualization of derisking renewable energy across the Caribbean, including initiatives mostly targeting the Eastern Caribbean, like the "Ten Island Challenge" (TIC) regional, Barbados "Disaster Risk and Energy Access Management" (DREAM), Dominica "Low Carbon Development Path" (LCDP) or the St. Vincent and the Grenadines "Promoting Access to Clean Energy Services" (PACES) projects that were listed in *Table 21* (above).

Other derisking applications also listed include the portfolio of projects the author oversaw and researched in both Haiti and Jamaica, on the Central part of the Caribbean region. These included both Haiti's Small Scale Hydro Project and the Climate Investment Funds' portfolio, and Jamaica's Renewable Energy and Energy Efficiency Deployment and Pilot Program for Climate Resilience portfolio.

These showed how Caribbean nations were increasingly aligning their plans and strategies with the post-2015 global policy agenda behind the COP21 Paris Agreement, the Sendai Framework for Disaster Risk Reduction, the Addis Abeba Action Plan on Financing for Development, and the 2030 Sustainable Development Goals (SDGs) agreed after the Rio+20 conference. These frameworks emphasized the kind of market transformations behind derisking renewable energy investment across and beyond SIDS.

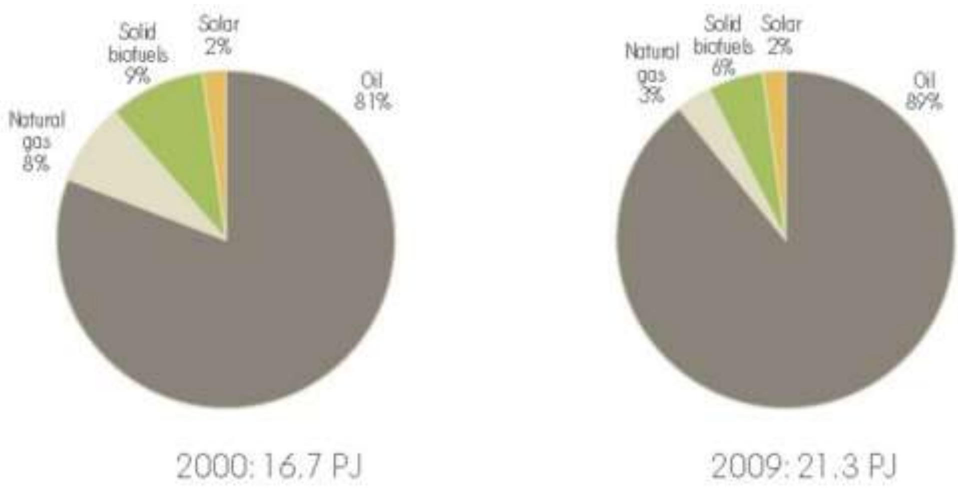
6.2 Barbados Disaster Risk & Energy Access Management

The Eastern Caribbean development agenda at the time the author started its desk and field research was shaped by various global policy frameworks and commitments, including the Millennium Development Goals that came out of the UN Millennium Summit in 2000, the Barbados Programme of Action and the Mauritius Strategy for the Implementation. Regionally, the Caribbean Community (CARICOM) further shaped the sub-region's development agenda emphasizing sustainable development across economic, social, environmental, and governance domains, with the Organisation of Eastern Caribbean States (OECS) focused on advancing human development in its constituent countries. Nationally, Barbados was a case for derisking for the post-2015 global agenda.

6.2.1 Barbadian Overview

With a land area of 431 km^2 and a population of 271,000 Barbados ranks high among LAC countries in social and economic indicators. Yet, despite efforts to promote renewable energy technologies, when the author visited the country, it remained 100% heavily reliant on fossil fuels – see *Figure 42* (below); the primary use of fuels was for power generation (50%), followed by transportation (33%), but while Barbados produced some oil, its domestic production of 1,000 barrels per day fell far short of the daily demand of 10,000 barrels (GEF, 2013c):

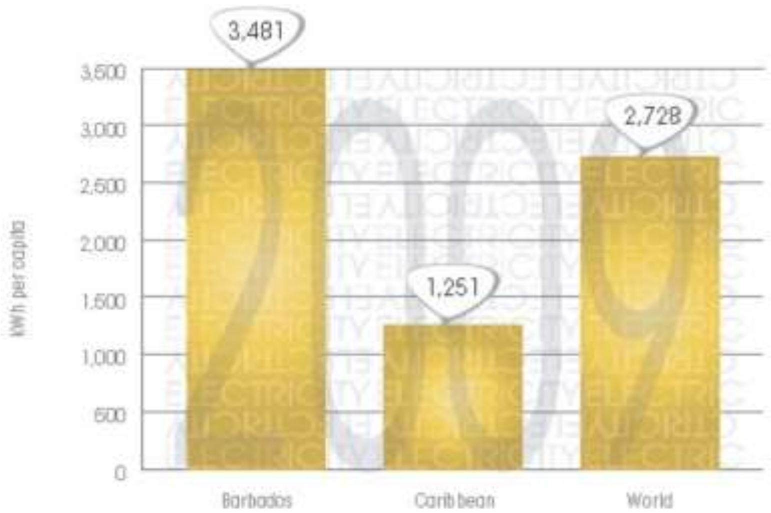
Figure 42: Barbados Primary Energy Supply 2000-2009



Source: GEF (2013c)

The volatility of oil prices was a significant challenge, particularly when oil prices peaked at USD 145 per barrel in 2008 – oil imports costed Barbados US$ 393.5 million, 6% of its GDP (ibid.). Rising energy costs were accompanied by a surge in electricity consumption, which grew by more than 50% between 2000 and 2008 (approximately 5.4% annually); in 2012, Barbados generated an estimated 955,000 MWh of electricity, while per capita electricity consumption reached 3,500 kWh/person in 2013 above global or regional averages (*Figure 43*, below):

Figure 43: Barbados Electricity Use Per Capita



Source: GEF (2013c)

Electricity costs in Barbados were among the highest in the region, averaging USD 0.40/kWh, with the Barbados Light and Power Company (BL&P) as the island's sole provider, generating, transmitting, and distributing electricity to 124,000 households. BL&P's installed electricity capacity was 239.1 MW, with a peak demand of 135 MW, and requiring 2.9 million barrels of oil annually (GEF, 2013c). Barbados lacks utility-scale renewable energy generation capacity.

The country's renewable energy production was confined to a few small solar PV and wind installations at households and experimental systems at government facilities. The most prominent application of renewable energy was solar water heating, which per Government of Barbados (GoB) and BL&P estimates, had achieved a 60% penetration rate among high- and middle-income households. In response to rising energy costs, the government prioritized energy conservation and efficiency across all sectors, supported by its National Energy Policy.

Barbados' energy sector was historically governed by the Electric Light and Power Act (1899) and the Draft Energy Policy (2008), with regulation under the Fair Trading Commission Act and Utilities Regulation Act. Responsibility for energy fell under the Prime Minister and a Minister of State. The GoB undertook several initiatives (listed below) to reduce its dependence on imported fossil fuels; however, in spite of these policy and programmatic efforts, the country still faced challenges, such as the need for further detailed strategic planning, grid stability assessments, and more efficient licensing processes (GEF, 2013c):

1. Adoption of the *National Strategic Plan (2006–2025)* to reduce fossil fuel reliance, to achieve penetration of solar water heaters in over half of households.

2. Approval of the *2007 National Energy Policy* to enhance energy security and transition to a low-carbon economy.

3. Creation of the *2010 Sustainable Energy Framework of Barbados* (SEFB) with the Inter-American Development Bank (IDB) to RE and draft the National Sustainable Energy Plan (NSEP), targeting 29% renewable energy by 2029.

4. Launch of the *2010 Renewable Energy Rider* (RER) pilot program to enable households and businesses to sell excess RE to the national grid.

5. Updates to the *Electric Light and Power Act* (2013, 2014) introduced licensing requirements for RE producers and allowed the enhancement of RE targets.

6. Introduction of tax breaks under the *Income Tax Amendment* (2013) to encourage RE and EE adoption and support training programs.

7. Budgetary allocations supported solar PV installations on government buildings.

8. Studies such as the *Intermittent Renewable Energy Penetration Study* (2014) evaluated the impact of variable renewable energy on grid stability.

9. Amendments in 2014 aimed to regulate RE installations and streamline the licensing process to reduce electricity prices and expand RE adoption.

6.2.2 Barbados Risk Environment

Solar PV systems were first introduced in Barbados to power remote telecommunications and navigational aids. By the late 1990s, the GoB sought to replicate the success of solar water heaters by implementing PV demonstration projects. By 2001, over 30 kWp of PV systems were installed across various sites, fully funded by the Ministry of Physical Development Environment, totalling 2.28 MW. The plan by mid-2015 was for Barbados to have total installed solar PV capacity of 12.92 MW, combining 2.28 MW from government installations, 5.5 MW from RER program and 5.14 MW on public buildings (GEF, 2013c).

The growing demand for PV systems under the RER program indicated the potential for surpassing the 2029 renewable energy target of 29% capacity or 70 MW as outlined by SEFB (ibid.). Lessons from other islands, like Martinique and Puerto Rico, demonstrated that favourable conditions could attract substantial private investment in large-scale PV projects. BL&P's 2012 plan initially capped intermittent renewables like solar and wind at 10% of peak demand due to grid stability concerns. However, modern solar PV systems and geographic distribution showed better reliability than historically expected.

With advancements in grid technology, Barbados could mitigate challenges of integrating large-scale renewable energy. Economic challenges limited the government's capacity to invest in large-scale renewable energy, particularly solar PV systems to realize these policy ambitions. This also had implications for disaster management, as hurricane shelters and other critical facilities required off-grid power. Solar PV systems could provide electricity for community-level needs, during disasters, but government resources remained insufficient.

Barbados was vulnerable to climate change with the country's 40 emergency shelters and polyclinics facing high risks of power outages during storms (e.g., jeopardizing lighting and operation of refrigerators for preserving medicines). The country needed to expand its RE use, especially considering that over 104.5 MW of BL&P's generating capacity was scheduled for retirement, and electricity demand was expected to grow by approximately 1.2% annually (GEF, 2013c).

The Department of Emergency Management under the Ministry of Environment, Science, Technology, and Innovation managed the functionality of buildings, including schools, community centers, polyclinics, and hospitals, designated as emergency shelters and relief centers during storms. These facilities typically relied on diesel generators for backup power, resulting in higher costs due to the use of fossil fuels. Community centers also served as hubs for other social purposes yet lacked reliable backup power. The GoB had planned to install stand-alone solar PV systems at emergency shelters and relief centers to enhance backup power availability during grid outages caused by severe storms. Budget constraints limited the GoB's ability to implement these systems broadly.

Barbados had successfully developed its solar thermal resources, creating a thriving solar water heating industry. However, this success was not replicated with other renewable energy technologies, such as solar PV. Since 2010, RE generation was capped at a cumulative 10 MW due to concerns about the impact of variable on the grid. Yet, the GoB committed to achieving a 29% of RE in the energy mix by 2029 (GEF, 2013c). In successive field visits to the country, and based on desk research and stakeholder interviews, Barbados faced several barriers to realizing the commercial potential of RE technologies, including: gaps in legislation, limited institutional capacity, low public awareness, and insufficient understanding of the impacts of VRE on the national grid.

Both the GoB and BL&P were uncertain about the extent to which VRE could be integrated into the grid, which hindered planning for RE growth. The lack of a strategy under the National Sustainable Energy Policy prevented policymakers from setting clear targets for installed RE capacity that would inform resource allocation, staff development, equipment procurement and local job creation. In addition, Barbados had an incomplete licensing framework for solar PV installations. The Department of Energy and Telecommunications required an updated review of procurement and installation practices to align licensing with international standards, strengthen local value chains, and account for environmental and social benefits. There was also uncertainty about the maximum level of VRE the grid could accommodate, as a key technical barrier.

Sudden changes in wind speed or solar irradiation would risk grid instability or failure without appropriate measures. Maintaining grid stability required adherence to standards for voltage, frequency, and component loading; evaluating the technology and costs needed to upgrade the grid remained a concern, as exceeding grid tolerance limits would lead to negative impacts. Thus, high penetration of VRE also required assessing the potential for such risks to materialize. Barbados lacked adequate technical analysis or power system modelling of VRE integration scenarios. Despite potential additional costs, RE generation and these measures was more cost-effective than fossil fuel options.

Resource limitations for RE development also hampered the recruitment and training of technical personnel within key government institutions to oversee critical tasks like grid stability analysis, investment recommendations for grid upgrades, RE target setting, and licensing for rooftop solar PV systems. Barbados also had a shortage of trained solar technicians in the local workforce, deterring investors to establish local businesses for the deployment of rooftop solar PV. Furthermore, public awareness about solar PV feasibility remained low, with outdated perceptions that it was an expensive alternative. Community-level awareness campaigns were often donor-funded, lacked sustainability, coordination, and follow-up. Few operational rooftop solar PV installations were available as demonstrations, which limited public confidence to promote them.

Finally, despite high electricity costs (USD 0.40/kWh) and falling global solar PV prices, the perception of high upfront costs remained a major deterrent in the Barbados market. While solar water heating had succeeded locally, solar PV adoption lagged. The national utility had limited incentives to expand RE generation. Its Renewable Energy Rider Programme, for instance, capped VRE inputs to 10% of grid capacity, which was reportedly oversubscribed. This indicated strong demand for RE but also reflected the artificial constraints imposed on the market by BL&P. Addressing these regulatory, technical, capacity, and financial barriers was essential to unlocking the full potential of renewable energy in Barbados. Comprehensive policy reforms, grid upgrades, public awareness campaigns, and investment in local expertise and resources would be key to driving sustainable RE growth.

6.2.3 Barbados Public Instruments

Barbados received support from the Inter-American Development Bank's (IDB) Programmatic Energy Policy-Based Loan (PBL). This was a key driver for advancing regulatory, policy, and legislative reforms in support of sustainable energy in Barbados. In 2010, the government had secured a US$ 45 million loan to implement the "Sustainable Energy Framework for Barbados (SEFB)" (GEF, 2013c). The loan supported climate adaptation measures, energy conservation efforts, institutional strengthening, and public education, along three objectives:

a) Reforming power sector regulations and enabling BL&P to purchase energy from RE providers, to enhance quality and reliability while reducing system costs

b) Promoting investments in cost-effective energy efficiency and renewable energy technologies through the establishment of the Energy Smart Fund

c) Installing 25 household PV systems and 3 PV systems for government institutions

These interventions were set to be completed, with a second PBL of US$ 70 million in the pipeline to support next-phase reforms focused on pending RE legislation and National Sustainable Energy Policy that would enable the diversification of the energy mix. SEFB was critical for deployment, yet its implementation faced challenges, and the author conceptualized further derisking support for the country as summarized in *Table 22* (below).

US$ 10 million were capitalized for the Energy Smart Fund comprising financial instruments and technical assistance to remove barriers to sustainable energy adoption. These instruments would include an US$6.5 million EE Retrofit and RE Finance Facility (i.e., revolving fund for commercial and industrial entities up to 50% of the costs for RE and EE projects); a US$ 0.5 million Technical Assistance Facility for pre-investment studies and RE and EE grants; and, a US$1 million Discretionary Facility supporting non-financial activities essential to increasing RE and EE adoption, such as public education campaigns, data collection, monitoring, and fund administration (GEF, 2013c).

Table 22: Barbados DREAM Project Derisking

Component	Pre-Derisking Scenario	Post-Derisking Scenario
1. Renewable energy policy framework	The GoB would continue in-kind support to implement the Barbados Sustainable Energy Framework (SEFB) and operationalization of associated policies, regulatory and legislative developments not in line with best practices given limited capacity for critical measures (e.g., licensing, VRE grid integration provisions) that can jeopardize the 29% RE 2029 target.	The GoB institutional capabilities strengthened to ensure the Barbados national grid would absorb VRE inputs over the short term, and the required hardware to increase the grid's capacity to absorb higher proportions of VRE in the medium and long term, supported by: (a) a grid stability assessment, (b) a strategic plan for phased grid upgrade investments, (c) a feasibility analysis for the GoB to finance grid upgrades, (d) a fully integrated licensing regime for solar-PV system installations per best practices internationally.
US$ 637,000	*US$ 260,000*	*US$ 377,000*
2. Clean energy capacity development	The GoB resources would be used to train solar PV technicians and professionals to manage a scaled-up installations program, but lack of general awareness of climate change and renewable energy due to limited institutional capacities would render these interventions unsustainable and ineffective to maximise these interventions.	The GoB focused installation of solar-PV panels on community and resource centres would strengthen position, resourceS and awareness of SEFB plans, its effectiveness not only for energy cost reduction, climate change mitigation, resilience or adaptation, but also community cohesion and job generation, with youth engagement, gender empowerment and increased employment benefits ramping up capabilities for safety, energy security and disaster risk response.
US$ 1,067,484	*US$ 790,000*	*US$ 277,484*
3. Solar photovoltaic system installations	The GoB would continue awarding contracts for grid-connected solar PV rooftop installations in government schools, health polyclinics, and community and resource centres seeking to leverage private sector investment. Yet, schools, community and resource centres and polyclinics serve as relief and/or emergency shelters during severe storm events that, while there is a programme for installing solar-PV to serve as backup power systems, they would still continue the use of diesel generators for main power. The GoB is unable to make solar PV the main power source until there are sufficient budgetary resources, so the country's vulnerability to disasters exacerbated by climate change and oil volatility is high.	The GoB successful demonstration of solar PV installations at public community and resource centres and polyclinics providing reliable backup power to these facilities during extreme storm events would strengthen investor's confidence and leverage private sector investment in the feasibility of solar and other renewable energy technology installations in Barbados. Further clarity in the GoB's strategic plans for RE scale-up based on enhanced knowledge of required investments to increase VRE into the national grid, and a strengthened licensing regime for RE technologies, local engineering companies in partnership with international firms as well as the national utility, which would be enabled to successfully implement a scaled-up program for grid-connected solar PV technology projects in Barbados, either as distributed or centralized generation. This would demonstrate GHG emission reductions, increased clean energy access, improved climate resilience, and cost competitiveness vis-à-vis existing energy bill.
US$30,922,000	*US$ 29,850,000*	*US$ 1,072,000*
US$ 32,626,484	**US$ 30,900,000**	**US$ 1,726,484**

Source: Author's contribution to GEF (2013c)

Without derisking the GoB faced barriers to meet its RE growth targets, technical, institutional and entrepreneurial constraints to scale up solar PV, uncertainties around VRE grid integration and independent power generation by private investors. Addressing these barriers were a key alternative to the grid-connected RE market unlikely to grow in the existing business model of BL&P sole control.

6.2.4 Barbados Levelised Costs

With the GEF-funded UNDP-supported derisking intervention costed at US$ 1,726,484 Barbados would achieve cumulative direct emission reductions of 276,895 tonnes of CO2 equivalent. This would include contribution to the installation of solar PV systems on the rooftops of 40 community and resource centres and 10 polyclinics, alongside co-financed solar panels from GoB plans.

Without the Barbados DREAM project or under a business-as-usual (BAU) scenario, these direct emission reductions would have been delayed until an independent grid stability analysis was conducted. This analysis would establish permissible levels of variable renewable energy integration and identify grid upgrade costs to ensure system stability. However, the project aimed at catalyzing solar energy development, resulting not only in greenhouse gas emission reductions from Barbados' energy sector, but also increased GoB confidence in increasing VRE contributions to the grid to attract investor interest and enhanced adaptation and resilience to the changing climate and increasing volatility of fossil fuel imports, hence fostering RE development.

Additionally, the project would enable the Energy Conservation and Renewable Energy (ECRE) division within the GoB to act as an investment facilitation centre, creating a favourable RE environment. This approach was estimated to yield indirect emission reductions of 718,400 tonnes of CO2 equivalent, assuming a causality factor of 40%, with an estimated GEF abatement cost for these reductions calculated at US$ 1.73 per tonne CO2 equivalent. Other replications would be subject to changes in ECRE and BL&P regulations for the introduction of new solar PV installations focused on maintaining grid stability, and lessons that would inform effective solar project implementation across SIDS globally. Understandingly, such transformation would require favourable RE investment conditions to equip ECRE and BL&P with knowledge on grid upgrades to integrate higher VRE inputs and expand RE deployment opportunities; provide oversight to ensure solar PV licensing and project proposals align with national economic and energy priorities; and maintaining a steady supply of trained solar PV professionals through awareness programs conducted at community centres.

6.2.5 Barbados Evaluation

The DREAM Project played a key role in strengthening energy sector governance and positioned the GoB and BL&P on a path toward enabling a more competitive, low-carbon electricity generation market. This progress was facilitated by the GoB baseline efforts and derisking support from international donors, including the DREAM Project and cofinanced programs. The project contributed to strengthening institutional capacity, reducing knowledge gaps amongst stakeholders and improving governance, in line with the result indicators summarized in *Table 23* (below) to increase RE adoption, reduce GHG emissions, and build resilience to disaster risks through access to clean energy:

Table 23: Barbados DREAM Project Indicators

GEF DREAM Project – Outcomes, Indicators and Targets						
Results Framework Level	Indicator		Unit	Baseline	Original Target	Revised Target
Objective: Promotion of increased access to clean energy in Barbados through solar photo-voltaic systems in government buildings to strengthen the country's climate resilience and disaster risk management	#1	Cumulative direct CO2 emission reductions resulting from the GEF intervention	(ton CO2eq)	0	276,895	–
	#2	RE-based electricity from the GEF intervention	(MWh)	0	316,090	–
	#3	Number of people using RE-based electricity	(-)	0	18,564	–
	#4	Share of RE in the power generation mix of Barbados	(%)	0	6.8%	–
	#5	Number of RE installations connected to the grid[28]	(-)	810	none	2,000
Outcome 1: Strategic plans and licensing regime approved for accelerated RE development	#6	Number of strategic plans completed for RE development in Barbados with targets and milestones	(-)	0	1	–
	#7	Number of grid stability assessments on VRE penetration into the Barbados grid	(-)	0	1	–
	#8	Number of RE licenses that received direct Project assistance	(-)	0	6	–
Outcome 2: Institutional and technical capacity and awareness strengthened for clean energy development	#9	Number of persons attending awareness raising sessions at community centres with regards to the benefits of rooftop solar PV installations that actively seek the introduction of RE	(-)	0	100	–
	#10	Number of persons under vocational training programs on solar PV technology and installations that are active in the RE sector	(-)	0	20	–
	#11	Number of tradespersons who have local certification to construct, assemble, operate, and maintain RE technologies that are actively providing ESCO-type/other services	(-)	0	50	(merged into indicator 2.1
	#12	Number of technicians trained in electrical grid monitoring and analysis[29]	(-)	??	none	20
Outcome 3: Feasible stand-alone solar PV electricity generation investments are successfully demonstrated	#13	Rooftop solar-PV installations financed through GoB RE funds where DoET and BL&P have involvement in operationalisation	(MW)	0	3.225	–
	#14	MW capacity of rooftop solar PV projects in planning and design stages	(MW)	0	7.5	–

Source: UNDP (2020)

In Table 24 (below), the DREAM overall achievements are outlined following the installation of 241 kWp solar PV systems on community resource centers, and polyclinics funded by GEF, complemented by 3,850 kWp installed by the GoB. It includes an achievement of 49% of climate change mitigation indicators (#1 and #2) based on projections, although based on the UNDP (2020) post-project evaluation and the author's corroboration these topline targets might be deemed as 100% achieved. This is based on the increase in total RE generation by 25.6 MW, which far exceeded the original target of 16.3 MW:

Table 24: Barbados DREAM Project Results

DREAM Project Overall Effectiveness			
Objective Indicator[61]	Target (RF)	Achieved (as of 31 Dec 2019)	Achievement (%)
Cumulative direct CO2 emission reductions resulting from the GEF intervention (#1)	276,895 tCO2eq (10 years)	136,400 tCO2eq (25 years)	49% (100%)
- from direct GEF investments in PV (241 kWp)		*8,050 tCO2eq*	
- from other investments by GOB (3,850 kWp)		*128,400 tCO2eq*	
RE-based electricity from the GEF intervention (#2)	316,090 MWh (10 years)	156,800 MWh (25 years)	49% (100%)
- from direct GEF investments in PV (241 kWp)		9,200 MWh (25 years)	
- from other investments by GOB (3,850 kWp)		147,500 MWh (25 years)	
Number of people using RE-based electricity (#3)	18,564 persons	36,300[62,63]	195%
Share of RE in the power generation mix of Barbados (#4)	6.8%	13.0%[64]	190%
Number of RE installations connected to the grid (#5)	2,000	1,923[65]	94%

Source: UNDP (2020)

As noted, the results derive from a combination of different sources of climate finance and co-financed interventions totalling over US$ 51.17 million, including:

(1) Public Sector Sustainable Energy Program with US$ 17 million from IADB and €5.81 million from the EU;

(2) Energy Smart Fund II with US$ 45 million from both;

(3) Technical Cooperation from Korea with US$ 3 million;

(4) UAE Caribbean Renewable Energy Fund with US$ 3.5 million for water pumping PV systems;

(5) Green Climate Fund Project with US$ 45.2 million for water resilience initiatives.

In addition, rooftop installations on private homes were privately funded, and other not tracked investments such as a 10-MW BL&P plant that came online, leading to a shift from rooftop to large-scale interventions. The DREAM project therefore successfully catalysed renewable energy adoption in Barbados, enhancing institutional capabilities and driving RE investments; laid the groundwork for long-term sustainability through knowledge sharing and policy alignment; and impacted the RE landscape, further detailed in *Table 25* (below):

Table 25: Barbados DREAM Solar PV Investments

Implemented PV capacities, Estimated Energy Production and GHG Emission Reductions													
RF Indicator	Description	Detail	PRODOC				PIR 2018	PIR 2019	End of Project				
			Capacity	Energy	GHG Reduction		Capacity	Capacity	Capacity	Energy		GHG Reduction	
			(MW)	(MWh / year)	(tCO2 / year)	(tCO2, 10 years)	(MW)	(MW)	(MW)	(MWh / year)	(MWh, 25 years)	(tCO2, 25 years)	(%)
#13 Rooftop solar-PV installations financed through GoB RE funds where DoET and BL&P have involvement in operationalisation (MW)	Grid-connected solar PV panels	40 community and resource centres with 2.5 kWp solar PV installations (purchased and installed by Project)	0.100	292	256	2,558	0	0.063	0.070	107	2,683	2,334	2%
		10 polyclinics each with 5 kW grid-tied system (equipment purchased and installed by Project)	0.050	146	128	1,279	0	0	0.171	267	6,665	5,798	5%
	Co-financed solar PV installations that benefit from TA from the Project including the grid stability analysis	150 kWp (438MWh/yr) at Gymnasium (Chinese Grant)	0.150	438	384	3,837	0.150	0.150	0.150	230	5,749	5,001	4%
		450 kWp (1,314 MWh/yr) at 3 Water Authority Sites (Chinese Grant)	0.450	1,314	1,151	11,511	0.400	0.400	0.150	613	15,330	13,337	11%
		75 kWp (219 MWh/yr) at 30 schools under EDF-11 Funding)	0.750	219	192	1,918	-	-	n/a	-	-	-	-
		DoET PPP for 2.5 MW on public buildings (7,300 MWh/yr)	2.500	7,300	6,395	63,948	-	-	n/a	-	-	-	-
		PSSEP - 13 government buildings						2.460	2.460	3,771	94,280	82,023	70%
		MEWR for 4 schools					0.040	0.040	0.040	61	1,533	1,334	1%
		Under Sustainable Energy Framework for Barbados (SEFB)					0.096	0.096	0.096	147	3,679	3,201	3%
		National Petroleum Corporation (NPC)					0.150	0.150	0.150	230	5,749	5,001	4%
		Other PV installations identified							0.310				
		TOTALS Indicator #13	4.0	9,709	8,505	85,051	0.836	3.359	3.850	5,902	147,551	128,370	100%
# 14 MW capacity of rooftop solar PV projects in planning and design stages (MW)		DoET PPP for 7.5 MW on public buildings (21,900 MWh/yr)	7.500	21,900	19,184	191,844			n/a	-	-	-	-
		TOTALS Indicator #14	7.5	21,900	19,184	191,844	0	0	0	0	0	-	-
		TOTAL	11.5	31,609	27,689	276,895							

Source: UNDP (2020)

For the DREAM-supported grid-connected solar PV interventions under results framework (RF) indicator #13 above, the GoB issued a tender for 40 Community and Resource Centres (CRCs). At the end of 2019, CRCs had installed a total capacity of 70 kWp of system sizes ranging from 2.5 kW to 7.5 kW. In the *Table 26* (below), a summary of key figures from all CRCs is provided for further reference; these include results relevant to the DREI model evaluation indicators that were assessed in other country case studies, and provide a snapshot of small scale outcomes that the DREAM project helped catalyse at larger scales:

Table 26: Barbados DREAM Solar PV Installations

PV Community Centres, Resource Centres and Pavilions - Key figures			
Investment (CAPEX)	939,142.40	B$	
	469,571	US$	
Specific investment cost	6,708.16	US$/kWp	
Usable hours	4.20	kWh/kWp, per day	
Energy production	294	kWh/day	
	107,310	kWh/yr	
	2,682,750	kWh	(25 year)
	2,682	MWh	
Monetary value (@.208 USD/kWh)	558,012	US$	total savings
	22,320	US$/yr	
Payback time	21.0	simple payback time (yr)	
GHG Emission reductions	2,334	tCO2 lifetime	
	2.33	kton CO2	

Source: UNDP (2020)

The GoB also enabled investments at polyclinics with key figures resulting summarized in *Table 27* (below). It required the conduct of site assessments to prepare tender documents for polyclinics after the completion of site visits to CRCs. The assessments gathered electricity bills, site plans, electrical panel directories, and basic roof evaluations while identifying locations for PV equipment, identifying monthly consumption ranging from 11,000 kWh for average-sized buildings to 25,000–40,000 kWh for the largest ones. The DREAM project expanded installations of 2.5-kW grid-tied PV systems to primary schools used as emergency shelters, including revisions to optimize functionality and reduce costs. All systems were ultimately installed and certified despite initial delays, contributing to improved emergency preparedness and energy efficiency.

Table 27: Barbados DREAM Solar PV Systems

PV Systems Polyclinics - Key figures			
Investment (CAPEX)	551,159.80	B$	
	275,580	US$	
Specific investment cost	1,584.70	US$/kWp	
Usable hours	4.20	kWh/kWp, per day	
Energy production	730	kWh/day	
	266,450	kWh/yr	
	6,665,000	kWh	(25 year)
	6,665	MWh	
Monetary value (@.208 USD/kWh)	1,386,320	US$	total savings
	55,453	US$/yr	
Payback time	5.0	simple payback time (yr)	
GHG Emission reductions	5,789	tCO2 lifetime	
	.80	kton CO2	

Source: UNDP (2020)

6.2.6 Barbadian Insights

Barbados achieved its objectives through policy and financial derisking interventions surpassing targeted kilowatt capacity. By reducing electricity bills, the upscaled systems offered cross-cutting benefits to the national goal of 100% renewable energy by 2030. Feed-in tariffs at the end of 2019 incentivized investments to ensure utilities purchased surplus electricity. The enhanced power supply for emergency shelters demonstrated the feasibility and multiple benefits of solar PV installations, contributing to national goals, optimizing future projects and shedding light on underutilized opportunities for energy efficiency.

6.3 Jamaica Solar PV and Energy Efficiency

Jamaica is SIDS that had a population of approximately 2.7 million, as the largest island in the Caribbean Cuba and Hispaniola (Dominican Republic and Haiti). It covers an area of 10,911 square kilometers (4,213 square miles), lying 140 km (90 miles) south of Cuba and 190 km (118 miles) west of Haiti (GEF, 2014).

The author undertook desk and field research in the country at a time it faced significant developmental challenges outlined in its Vision 2030 National Development Plan, such as its high dependency on imported petroleum and inefficient energy usage. For instance, as summarized in *Table 28* (below), around 90% of Jamaica's energy needs were met by fossil fuels, with the electricity sector consuming over one-third of its oil imports. Approximately 95% of the installed electrical capacity relied on oil, with electricity costs averaging $0.25 per kWh; in 2014, Jamaica spent US$2 billion on imported oil, about 15% of its GDP, making it the fourth highest in electricity prices among CARICOM nations, excluding Belize, the Dominican Republic, and Montserrat (GEF, 2014):

Table 28: Jamaica Energy Mix

SOURCE	BOE	BOE	% MIX
Petroleum Imports		21,214,652	**95.3**
Coal Import		327,000	**1.5**
Renewables			
Hydro	*94,000*		
Wind	*57,000*		
Charcoal	*n/a*		
Bagasse	*570,000*		
Fuel wood	*n/a*		
		721,000	**3.2**
GRAND TOTAL		**22,262,652**	**100.0**

Source: GEF (2014)

Its reliance on imported fossil fuels and vulnerability to oil price fluctuations significantly affected Jamaica's economy, particularly the manufacturing sector. The country was endowed with valuable natural assets, including arable land, scenic beauty, diverse biodiversity, and modest mineral resources. Historically economic growth was driven by tourism, sugar production, banana exports.

6.3.1 Jamaican Overview

Jamaica's renewable energy sources included wind, hydropower, and bagasse, with the electricity sector heavily reliant on inefficient fossil fuel plants. Efforts to cut public sector energy use and expand renewables were hindered by limited implementation, despite high costs and economic vulnerability caused by fossil fuel dependence. Gender exclusion in energy planning and limited investments in sustainable energy further challenged progress. The National Energy Policy outlined ambitious targets and a supportive policy framework to drive renewable energy growth and environmental sustainability by 2030. The country derived renewable energy primarily from wind, hydropower, fuelwood, bagasse, solar, and ethanol, particularly in the transportation sector; however, the electricity sector consumed the highest volume of petroleum, approximately 6.5 million barrels (30.8%), due to reliance on outdated and inefficient power plants (GEF, 2014). Only 5.6% of the electricity supply came from renewables such as hydro, wind, and limited biomass for heat and power; the distribution of renewable energy sources included 13% hydropower, 7.9% wind, and 79% bagasse (ibid.).

The Jamaican government aimed to reduce public sector energy consumption by 15% through improved energy efficiency and renewable energy technologies; for instance, in 2012 the public sector's electricity bill reached J$15.4 billion (US$171.1 million) with an energy consumption of 477 GWh. Despite the health sector accounting for 6% of this cost (J$919.171 million or US$10.2 million) and consuming 30 GWh annually, minimal sustainable energy investments had been made. Despite a prior audit of 22 hospitals identified opportunities for renewable energy and efficiency improvements, the recommendations did not lead to implementation. The economic reliance on fossil fuels, constituting one-third of imports (15% of GDP), significantly hindered investment, reduced disposable household income, and strained government spending on critical social sectors like education and health (ibid.). Energy demand primarily came from households, commercial services, industries, and transportation, with high electricity costs exacerbating vulnerability, for small businesses and low-income households.

In addition, the Jamaica's Sustainable Energy Road Map (2013) noted limited gender inclusion in energy-related fields, as traditional roles often excluded women from decision-making and technical opportunities. Though most households accessed electricity and modern fuels, women were marginalized in energy planning. Addressing gender inequalities in sustainable energy access and job creation was identified as critical to Jamaica's energy transition.

The National Energy Policy (2009–2030) envisioned a modern, efficient, and sustainable energy sector ensuring affordability, accessibility, and long-term security. This vision was supported by goals emphasizing energy conservation, renewable sources, reduced greenhouse gas emissions, and a robust governance framework – see below targets (*Table 29*); with supplementary policies including waste-to-energy, biofuels, and carbon credit trading, amongst other plans:

Table 29: Jamaica Renewable Energy Targets

INDICATOR	2009	2012	2015	2030
Percentage Renewables in Energy Mix.	8%	11%	12.5%	20%
Percentage Diversification of Energy Supply.	9%	11%	33%	70%

Source: GEF (2014)

However, Jamaica's reliance on outdated diesel-based energy systems and exposure to volatile oil prices strained its economy, limiting resources for essential social services and renewable energy investments. With one of the world's highest electricity tariffs, Jamaica faced increasing pressure to adopt renewable energy solutions. Budget constraints and systemic barriers—including regulatory, technical, and financial challenges—hindered the expansion of renewable energy and energy efficiency initiatives, despite growing interest from stakeholders in mitigating high energy costs.

The slow development of renewable energy, as in many other CARICOM nations, was primarily attributed to its SIDS status, with limited scalable markets. Yet, fluctuations in global oil prices kept exposing Jamaica's economic vulnerability, reducing foreign currency reserves, disrupting it balance of payments, and limiting funding for critical social sectors, after the 2008-20009 oil price spikes.

6.3.2 Jamaica Risk Environment

Jamaica's electricity grid, although larger than those of several CARICOM nations, was relatively small and lacked interconnection with neighbouring islands. Rising interest from donors, the government, and the private sector highlighted the potential of renewable energy as a solution to mitigate high energy costs. Budgetary limitations made it difficult for the government to invest in decentralized solar PV systems and other renewable technologies for the public sector. Lowering electricity costs for public facilities became urgent, with solutions focusing on solar PV, solar water heating, and energy efficiency. Yet, several barriers summarized in *Table 30* (below) hindered the scaling of RE and EE in Jamaica, specially solar PV, along three main broad categories:

Table 30: Jamaica RE and EE Barriers

Barrier type	**Barrier Descriptions**
Regulatory Policy / Legal: *Limited enforcement of provisions for RETs and EE*	• Limited enforcement of energy performance standards for RETs and EE equipment enshrined in the NEP • Lack of uniform net-metering and interconnection standards for small-scale power generation units (SPVs) • Absence of clarity on licensing processes and billing arrangements for off-grid/on-grid/self generation • No building code enforcement for items such as solar water heaters, amongst other equipment • Absence of penalties for not meeting renewable energy targets in the National Energy Policy • No restrictions on the quality and other features of RETs/EETs (e.g. life-cycle cots, wattage)
Institutional / Technical: *Limited awareness of the benefits of RETs and EE products*	• Limited technical expertise in public sector institutions (particularly in Jamaica's health sector) tasked to oversee electricity equipment purchases and performance (e.g. quality standards, cost-benefit analysis) • Public generation and grid system losses (both technical and non-technical) exceeding the total renewable energy produced, contributing to high electricity prices to absorb inefficiencies • Lack of critical mass of certified RE/EE students, installers and entrepreneurs to address the demand for energy savings and performance contracts (i.e. ESCOs) required to address it
Market / Financial: *Lack of incentives for investment in clean energy / efficient products*	• Despite high electricity costs (nearly US$0.40/kWh), the upfront cost of SETs & EE in buildings/lighting deters investment more clean electricity/energy efficient equipment in most public hospitals • Higher-quality EE & SET products are too expensive, so most hospitals buy conventional incandescent lamps, inefficient air conditioning, and cheaper/lower quality solar PV panel types • Lack of fiscal, economic or other financial incentives to promote low carbon development investments • Lack of dedicated grants or soft loans for relevant research, development and exploration

Source: Author's contribution to GEF (2014)

Regulatory, Policy and Legal Barriers

Jamaica's outdated legal and regulatory frameworks, coupled with delayed modernization efforts, hindered renewable energy development. Key barriers included a lack of quality standards, inconsistent interconnection procedures, and inadequate training for installers. Testing capabilities for energy-efficient devices were also insufficient, with limited resources at the Bureau of Standards Jamaica. Initiatives like Net Billing showed potential for cost savings but faced challenges due to regulatory gaps. Efforts to address these issues, including capacity-building programs, were critical to advancing energy efficiency and renewable energy initiatives. Jamaica's legal and regulatory frameworks governing the power market were outlined in several key documents.

This included the Office of Utilities Regulation Act of 1995, and the Electric Lighting Act, Jamaica Public Service Company Amended All-Island Electric License of 2011; although the Electric Lighting Act of 1958 and related Building Regulations included provisions for renewable energy development, their outdated nature and lack of secondary legislation impeded implementation (GEF, 2014). Efforts to repeal and modernize these laws aimed to incorporate new energy efficiency standards in building designs, but delays hindered progress. The absence of a modern building code or binding energy performance standards limited public, private sector adoption of energy-efficient practices.

Ineffective legislation and delays in repealing outdated laws were significant barriers. Critical gaps included the lack of mandatory quality standards for solar water heaters, provisions for net billing, interconnection standards, and performance criteria for small-scale power generation. Net billing, for instance, while it offered potential savings by aligning daytime energy use with on-site distributed generation, faced challenges due to inconsistent interconnection procedures and untrained installers. These deficiencies, highlighted by the Government Electrical Inspectorate and the Jamaica EU-ESCO project, posed risks to public sector renewable energy projects. Additionally, inadequate testing by the Bureau of Standards Jamaica of grid-connected components (solar water heaters and energy-efficient equipment) further undermined quality assurance.

Institutional and Technical Barriers

Jamaica had 16 MW of installed solar PV capacity, used mainly for specific applications like rural electrification and street lighting. Despite the country's solar potential, with average global horizontal irradiance (GHI) range of 5 to 8 kWh/m2/day, far exceeding the highest GHI in solar PV installation leaders like Germany (3.5 kWh/m2/day), i.e., Jamaica's GHI– see *Figure 44* (below), the country's solar PV market was highly underdeveloped (GEF, 2014); here, expanding the sector required investments in technical training, foreign direct investment, and fostering inclusivity to create job opportunities and support market growth; failing which risked slowing progress in RE and EE development:

Figure 44: Jamaican Solar Map

Source: GEF (2014)

One barrier identified to capitalize on this potential was the limited technical skills in the solar PV sector, from design, assembly, installation to maintenance. While some technical expertise existed, additional training was required to meet market demands and ensure quality service delivery. This constraint also limited RE market expansion, foreign direct investment attraction, workforce development and talent retention of locally trained, certified solar technicians. Without efforts to build this technical capacity, Jamaica risked losing market creation opportunities for RE and slowing the growth of its solar PV market. Particularly, in a male-dominated field, efforts to grow the renewable energy and energy efficiency sectors needed to women empowerment, youth engagement.

Market and Financial Barriers

The high upfront costs associated with RE and EE investments posed significant challenges, often requiring debt financing. Yet the lending market for RE and EE was relatively undeveloped, and financial institutions lacked sufficient understanding of the associated risks, opportunities, and paybacks, leading to unfavourable lending terms (e.g., high interest rates, stringent collateral requirements, short loan tenors). It discouraged many consumers from pursuing loans, in particular for low-income groups with limited access to financing, despite the potential benefits of reduced electricity costs. While Jamaica had a well-established financial sector comprising national banks, credit unions, and international banks, which offered debt financing to residential, commercial, and industrial sectors, loans specifically for RE and EE investments were minimal.

During the author's field visit and project development process, the Bankers Association of Jamaica acknowledged that the market for RE and EE lending was growing very slowly, due to concerns over technological obsolescence, general lack of awareness about the short-term benefits, and paybacks of these investments. The Development Bank of Jamaica (DBJ) offered low-interest loans for energy audits and retrofits, but fiscal incentives for clean energy adoption were lacking. Public sector investments in RE and EE were further constrained by International Monetary Fund (IMF) restrictions on capital expenditures and debt. The author's research contributions in other Caribbean countries, such as the Saint Lucia and Belize (IMF 2018a and 2018b), corroborated the impact of these macroeconomic and fiscal limitations in SIDS amidst a changing climate.

As a result, RE and EE projects were excluded from public sector budgets, and this was under the IMF requirement to reduce public sector investment by 10%. The benefits from RE and EE investments due to high upfront costs would be delayed, also constrained by limited expertise and time among public sector entities to assess long-term trade-offs. In addition, there was insufficient testing of alternative financing models like Energy Performance Contracting (EPC) or third-party ownership in Jamaica, when globally EPC models have been widely adopted to address similar challenges in public sector RE and EE investments.

The broader Caribbean region had made notable progress in renewable energy adoption over the past decades, supported by initiatives such as the Caribbean Energy Information System (CEIS) for public awareness. Nevertheless, gaps remained in public and private sector awareness of RE and EE benefits, and financial institutions continued to lack sufficient knowledge about these technologies. DBJ provided leadership in promoting RE adoption, but investment remained limited due to lack of education and accessible RE and EE information.

6.3.3 Jamaica Public Instruments

Throughout the research period the author's desk, field research and stakeholder engagements has seen different derisking instruments applied by governments to enable the adoption of renewable energy and energy efficiency including regulatory mandates, tax incentives, financial instruments, and collaborations with private utilities.

Regulatory measures included mandates for renewable energy generation, building codes, and procurement standards; tax policies offered exemptions, rebates, and credits to incentivize the adoption of energy-efficient technologies; financial instruments have included concessional loans, guarantees, bulk procurement programs, and energy performance contracting; meanwhile, private utilities have collaborated with governments to provide on-bill financing, rebates, and demand management services. In the RE and EE Jamaica project context, these instruments were implemented in various ways, as follows.

Jamaica's baseline instruments included regulatory targets, such as achieving 12.5% RE in the energy mix by 2015 and 20% by 2030 (as well as CARICOM's 47% RE target by 2027). However, challenges remained in ensuring compliance with environmental regulations, integrating life cycle cost considerations into procurement, and enforcing green procurement guidelines. The Bureau of Standards tested imported appliances to establish baseline standards, but the application of renewable energy generation policies such as net billing and interconnection standards varied. While voluntary energy codes were in place, mandatory codes were yet to be fully implemented.

Tax exemptions for energy-efficient products and various green loans were available through programs offered by the DBJ and other lending institutions. Despite these, public sector RE and EE investments were hindered by IMF restrictions on debt and the absence of bond issuance as a financing option. Grant programs, such as DBJ's Energy Audit Grants, provided up to J$200,000 for audits targeting micro, small, and medium enterprises. Energy performance contracting was identified as a potential mechanism to facilitate RE and EE adoption.

Although the Petroleum Corporation of Jamaica (PCJ) planned to establish an ESCO model, public sector leasing for RE and EE projects faced restrictions from the Ministry of Finance, which treated such agreements as liabilities. Jamaica also lacked on-bill financing and rebate programs. A demand-side management pilot program (1996–1999) was conducted, including public awareness campaigns.

However, Jamaica's heavy reliance on imported petroleum negatively impacted the economy, environmental sustainability, and the government's ability to invest in essential services such as health and education. This underscored the urgent need for a transition to sustainable energy technologies. The National Energy Policy (2009–2030) set a goal of achieving 20% renewable energy in the energy mix by 2030. It also aligned with the Vision 2030 National Development Plan, which emphasized energy security and efficiency.

Several government policies and programs were designed to support energy security and the transition to sustainable energy, including the Jamaica Sustainable Roadmap. These initiatives were developed in consultation with key ministries and stakeholders, highlighting the government's commitment to expanding energy access, and reducing fossil fuel dependency. The GEF-funded, UNDP-supported Jamaica "Deployment of Renewable Energy and Improvement of Energy Efficiency in the Public Sector" (DREIEE) was such an intervention. The author conceptualized this project as UNDP Regional Technical Advisor in consultation with the Government of Jamaica to advance a low carbon development path and reduce the public sector's energy bill, with particular focus on the health sector. The specific derisking measures are summarized in *Table 31* (below), to address the main barrier categories identified before:

Table 31: Jamaica DREIEE Project Derisking

Component	Pre-Derisking Scenario	Post-Derisking Scenario
1. Individual and institutional RE and EE knowledge and capacity strengthening in Jamaica's public sector	Hospital and other public investment packages were identified but the critical mass of local experts and entrepreneurs (i.e. ESCOs) required for the private sector to absorb additional public and industry demands for their energy performance services did not exist. Parallel initiatives (e.g. GEF/UNEP EE project) were only focused on building performance.	Capacity development efforts through training on RE and EE (e.g. solar water heating and photo voltaic, and energy efficient air conditioning and LED lighting) equipment, system and product installation, technical certification and inspection in the Jamaican health sector, which would help raise awareness on the benefits (low carbon, energy savings, sustainable development) of undertaking similar investments in other hospitals. The focus on appliances broadened the training scope to students, technicians and entrepreneurs to promote employment.
US$956,483	*US$856,483*	*US$100,000*
2. Regulatory developments for the deployment of RE and EE promotion in Jamaica's public sector	National energy policy action plan # 2 for the period 2013-2016 was set to implement Jamaica's 2009-2030 energy policy goal of fuelling the country's growth down a low carbon path; however, its priority project on strengthening the policy, legislative and regulatory framework provides for enforcement mechanisms was yet to be developed.	Introduction and enforcement of licensing, net billing, audit inspection, certification and minimum energy performance standards of RE and EE equipment, systems and products (e.g. solar water heating and photo voltaic, and energy efficient air conditioning & lighting) in the Jamaican health sector applicable to the rest of the public and commercial sector (e.g. private hospitals, public buildings, tourism) would contribute to the effective implementation of national energy policies, and its contribution to sustainable low carbon development.
US$784,887	*US$584,887*	*US$200,000*
3. Economic and fiscal instruments for the uptake of RE and EE technologies in the Jamaica's public sector	The Petroleum Corporation of Jamaica and National Health Fund were making provisions (US$1.2m of which US$0.9m was cash and the remaining was PCJ's in-kind from the US$5.5m national government contribution) to promote RE and EE interventions that were insufficient to match the investment requirements estimated for the hospital program. The available IDB funding (US$4m) could address the shortfall with additional incentives to scale up the investment program.	De-risking measures introduced by the project catalyze RE and EE programs nationwide (including bulk procurement, energy performance and savings contracts, amongst others that would be confirmed during the preparatory phase), would contribute to the development of additional investment packages for the public sector and eventually the private sector that the critical mass of local companies (i.e. ESCOs) could absorb. The electricity cost savings materialized (given the short payback period to recover the initial outlay) would help Jamaica address the macroeconomic risks and uncertainty over uptake of RE and EE technologies, given IMF's restrictions on government spending.
US$10,262,371	*US$9,307,384*	*US$954,987*
US$ 12,003,741	**US$ 10,748,754**	**US$ 1,254,987**

Source: Author's contribution to GEF (2014)

A portion of this support was planned to be financed through a soft loan from the Inter-American Development Bank (IADB), with US$4 million allocated to provide technical assistance for the design, implementation, and knowledge management of similar RE and EE investments. This funding was contingent upon the successful demonstration of benefits to facilitate future scaling of such investments. The additional GEF-funded, UNDP-support DREIEE intervention was aimed to address the barriers preventing the realization of further funding.

6.3.4 Jamaica Levelised Costs

This effort targeting the health sector was intended to serve as a model to be replicated in others. The initial implementation targeted 10–15 public hospitals, to overcome investment constraints and pave the way for nationwide replication. In its Component 1, the DREIEE project was designed to address the lack of technical knowledge, capacity, and awareness about the economic, social, and environmental benefits of solar energy technologies (e.g., water heating and PV systems) and energy conservation measures (e.g., EE air conditioning and lighting), with training and on-the-job learning through demonstration projects involving these technologies. Capacity development and awareness-raising efforts aimed to secure government support and financial commitments.

In its Component 2, the DREIEE project facilitated the development of legal instruments and provisions to promote the adoption of RE and EE technologies. These included the development of a codified licensing and certification System. The aim was to establish and adopt a formal system for licensing, net billing, inspection, and certification of RE and EE technologies in Jamaica's health sector. Enforcement mechanisms were designed to integrate with Jamaica's broader energy policy and extend to other public and commercial sectors, including private hospitals, tourism, and public buildings. The project also supported the implementation of new rules for net billing and installation inspections, developing processes and criteria for the promotion of solar water heating, PV systems, energy-efficient lighting and air conditioning.

Finally in its Component 3, economic and fiscal Instruments for RE and EE in were introduced, including tax breaks, rebates for ESCOs, bulk procurement for the health sector, and energy performance contracts. Collaborations with financial institutions like the IADB and other co-financiers supported investment packages tailored to the health and public sectors (solar water heating, PV systems, EE air conditioning and lighting). The project aimed at 1 MW of SWH and PV capacity, along with retrofits for efficient indoor, outdoor, and street lighting, estimated to generate 37 GWh in energy savings and avoid 33 ktCO_2 of direct emissions and 349 ktCO_2 of indirect emissions – see *Table 32* (below):

Table 32: Jamaica DREIEE Project Emissions

GHG emission reduction	Activity * *Emission Factor:0.9 tCO2e/MWh (avg.)* ** *Load Factor Range: 12-33% (2-5kWp systems)*	Annual energy output (MWh)**		Total energy saving / generation, MWh	GHG emission reduction, tCO_2e*		Unit Abated Cost (US$ / tCO_2e)
		BAU	Project		Annual	Total	
Direct ***	Solar energy technology (SWHs/SPV system) installations (32 x 5kWp) in 5-10 hospitals	-	465	1,870	415	1,675	
*** *4yr project lifetime*	Energy efficiency retrofits/new fixtures (A/C units, 150w HPS / LED products) in 5-10 hospitals	-	955	3,815	860	3,430	
	Public sector programs (SET installations, EE new fixtures/retrofits) in approx. 15-30 public buildings	-	7,930	31,700	7,130	28,530	
TOTAL Direct:						**33,635**	*44.09*
Indirect	Policy and financial de-risking for EEL / solar PV (10MW) investments (60% causality)	-	29,200	350,400	26,280	315,360	***4.70***
TOTAL Direct + Indirect:						**348,995**	*4.25*

Source: Author's contribution to GEF (2014)

During the 4-year project, estimated savings of US$1 million associated with the DREIEE project were anticipated to facilitate the use of a US$4 million loan provided to MSTEM for further RE and EE investments in the public sector beyond the health sector. They expected to help bridge the financing gap and alleviate restricted investments in health and other social sectors, considering the high cost of electricity. Benefits at the then estimated cost of US$0.50/kWh included: (a) a reduction in solar PV costs to US$0.30/kWh or less; (b) a payback period of 2-4 years for energy-efficient air conditioning; and (c) a payback period of 3-9 months for solar water heating/pumping and energy-efficient lighting (id.)

6.3.5 Jamaica Evaluation

The DREIEE project supported the strengthening of Jamaica's institutional and governance frameworks for renewable energy and energy efficiency interventions. However, financial sustainability remained uncertain, relying heavily on the development of effective financial mechanisms for maintaining RE and EE interventions. The inability to establish a functional energy performance contracting model posed a risk to the financial sustainability of the project. The project facilitated national discussions on energy performance contracting and energy service companies, it did not establish a functional EPC or ESCO model. Part of this risk was due to the dissolution of the Petroleum Corporation of Jamaica in 2019. However, institutional and governance frameworks were deemed strengthened. The project aided the government in raising awareness among over 80 health sector operators regarding energy management and renewable energy technologies.

It enhanced the standards of solar PV system installation and maintenance through targeted training for more than 30 technicians. It also delivered training on financing and investments in RE and EE projects to financial intermediaries and representatives of service providers and developers. Following an assessment of post-secondary sustainable energy, minimum expected standards for these programs was established. This initiative supported by the DREIEE project was well received by the Jamaica Tertiary Education Commission, which engaged leading national universities in discussions about creating a framework for RE and EE curricula, and improving quality standards in tertiary education. The project also contributed to restructuring the tertiary education system and provided institutional support by procuring a power generator for the Bureau of Standards Jamaica (BSJ) EE testing laboratory.

The project provided further assistance to the BSJ by supporting the revision and updating of sections of the Building Code. It also developed and reviewed an Energy Efficiency and Conservation Standards Guide for the Public Sector. The guide served as a resource for public sector managers, enhancing procurement practices and increasing awareness of energy efficiency standards. The project also facilitated the creation of National Guidelines for Solar PV Operations and Maintenance, which were submitted to the BSJ for approval and adoption. These guidelines served as a reference for solar PV system installers, users, and maintenance personnel. Other contributions included developing energy efficiency and conservation standards for the public sector and conducting a qualitative assessment of Jamaica's ESCOs market. The project commissioned investment-grade energy audits at six healthcare facilities. Following the audits, these facilities were retrofitted with over 6,000 high-quality energy-efficient LED bulbs. Additionally, rooftop solar PV systems were procured, installed, and commissioned for three other facilities. The solar PV systems, with a total installed capacity of 172 kW, were projected to generate 211 MWh of electricity annually, while the energy efficiency retrofits were estimated to save 851 MWh per year. These interventions were expected to reduce GHG emissions by 3,320 tCO2eq for solar PV systems and 4,749 tCO2eq for energy efficiency retrofits.

6.3.6 Jamaican Insights

Jamaica's experience demonstrates that renewable energy transition in small, import-dependent economies is constrained not just by finance, but by social and institutional barriers. Gender exclusion and technical skill shortages limited the capacity for change, while fossil fuel lock-in and policy gaps deterred investment.

Gender exclusion, for instance, reduced the social acceptance and innovation potential of a renewables-based energy transition. Women, particularly in rural areas, were often excluded from capacity-building programs. As primary household energy managers, their exclusion limited the scaling of decentralized solar and bioenergy solutions. It contributed to the broader lack of technical skills that hindered domestic industry development, and the scarcity of local installers and engineers, which delayed project commissioning. It reinforced dependency on foreign external expertise and increased O&M costs.

Fossil fuel lock-in had a negative on renewable energy investment. Jamaican electricity prices tracked global oil prices, such that when oil prices fell, renewables became less competitive undermining investor confidence. Legacy contracts with oil importers and generators increased lock-in effects, with guaranteed capacity payments to fossil fuel plants crowding out RE investments. The grid's baseload configuration was optimized for thermal power, making it costly to dispatch intermittent renewables. High energy import bills limit public resources for RE incentives, grants, or R&D. Taxes from fossil fuels created policy disincentives to accelerate RE transition against decreased government revenue. Finally, fossil-fuel--linked PPAs and Jamaica's macroeconomic instability inflated the perceived risk for renewables, with investors demanding higher returns.

The National Energy Policy set the right vision, but effective financial, institutional, and social derisking remained the missing link for achieving Jamaica's renewable energy targets due to a range of challenges. First, financial and economic challenges included a high cost of capital and Jamaica's investment-grade risk profile, which was fragile at the time and led to high interest rates, with limited access to concessional finance. This led to an increased average cost of capital that exceeded 10–12%, inflating project LCOE.

The small Jamaican market size, with limited domestic demand reduced economies of scale for utility-scale RE projects, which together with foreign exchange exposure increased the currency risk of imported RE equipment. Second, institutional and regulatory challenges included implementation gaps: of the NEP set, with inconsistent follow-through due to bureaucratic delays, fragmented mandates, and weak enforcement capacity. Additionally, grid integration constraints were linked to the Jamaica Public Service Company (JPS) as the sole transmission operator slow adapting grid codes to variable renewables. Finally, complex independent power producer licensing and tendering procedures led to procurement delays that deterred new entrants.

Third, technological and infrastructure barriers related to grid stability concerns, due to limited energy storage, and outdated grid infrastructure constraining the integration of intermittent solar and wind power. It exacerbated Jamaica's dependence on diesel-based backup systems to stabilize grid frequency. Finally, human capacity challenges included limited technical skills due to a shortage of trained engineers and technicians in RE; women underrepresentation in the workforce; and its limited diffusion in local innovation ecosystems and entrepreneurial value chains.

That said, the NEP played a key role in setting Jamaica's renewable energy targets. The NEP had clear limitations in that these targets were not binding, and thus Jamaica's renewable energy goals were aspirational, not enforceable; weak energy sector coordination amongst the Ministry of Science, Energy and Technology, the Petroleum Corporation of Jamaica, and JPS; and, inadequate monitoring with limited periodic reviews and data transparency. But it did provide Jamaica's first comprehensive framework for energy diversification.

It set the direction of travel to reduce dependence the country's dependence on imported petroleum; promoted renewable energy development; encouraged private sector participation; and improved energy efficiency and security. It established a legal and strategic foundation for renewable investments, and created the Electricity Sector Enterprise Team that streamlined investment processes, enabling the Wigton Wind Farm (62 MW, largest in the Caribbean).

As key strategic lessons to be drawn from Jamaica's experience, the stability and transparency of policy frameworks is critical. Yet, targets must be backed by enforceable instruments and streamlined procurement processes. The resulting energy diversification reduces vulnerability and fossil dependence through renewables, stabilising tariffs and improving energy security, particularly relevant in small island development states.

The joint human and physical capital dimensions are also important. Technical training and gender-inclusive programs can accelerate market maturation. Grid modernization is a also prerequisite, with storage, dispatch management, and digital monitoring systems needed to accommodate renewables, and the workforce to make the energy transition a reality.

Here policy and financial derisking are both essential. They ultimately can help lower the cost of capital, and make renewable energy investment more competitive than fossil fuel-based conventional sources.

7

7 Adaptation Potential of the NWHRM and DREI Approaches

7.1 Variation of Model Dimensions

Research so far suggested that both NWHRM and DREI models were applicable to mature alternative renewable energy resources (particularly, hydro and wind power). However, the evidence from wind and wave energy developments in Europe and globally, in addition to comparative research in Africa (specially, concentrated solar power developments in Namibia and South Africa) shows that nascent renewable energy technologies required policy and financing de-risking measures before their full commercialization. Based on the research findings from comparative renewable energy developments in emerging markets and development countries, the DREI and NWHRM would require variations.

These variations would include adaptations in accordance with the EU sustainable finance strategy on dimensions, such as the: (a) carbon intensity thresholds (per the EU taxonomy regulation); (b) green finance eligibility (per the green bond standards); (c) significant harm provisions (per other EU environmental objectives). Based on the case studies explored so far, i.e. 2-10MW hydropower plants in Sub-Saharan Africa (Equatorial Guinea), compared to large-scale developments in South America (Paraguay) and Central Asia (Tajikistan), further analysis is required to identify adjustments related to scale.

7.2 Inclusion of Human Capital Dimensions

People were not seen as a resource in the NWHRM. The key one was hydrological, as it influenced turbine options depending on demand and environmental considerations. However, people were seen as a resource in the PhD thesis, not only as part of social acceptability, but also critical in the implementation support and/or decision-making required in emerging markets and developing economies making energy choices available (fossil versus green).

In the NWHRM rationale: "The information is linked through an economic assessment which identifies different turbine options, assesses their suitability for location and demand and combines the different styles of information in a way that supports decision making."

In the thesis rationale, there is a parallel that can be drawn as the people dimension assessment considers various factors (e.g., labour supply and demand, roles and skillsets, age and gender) that can influence energy transition pathways (e.g., from coal, oil or gas to hydropower, solar or wind power). The labour risk factor was indeed considered in the DREI framework, yet not in its dimensions.

In a way, that same decision-making decision process was applicable in both developed countries and emerging market and developing economy contexts, with economies considering their comparative advantage not only based on natural but also human resource options (e.g., UK and European competitiveness in offshore wind power, versus African competitiveness in solar power).

At the international level, the question has also arisen in successive climate negotiations. There countries around the world face a crucial decision between ensuring energy security and transitioning to sustainable energy. This dilemma is particularly relevant in EMDEs, where the costs and benefits of this choice are directly felt. The war in Ukraine has driven up oil and gas prices, leading to significant changes in the global energy system (Bond, 2022). At the same time, this crisis has sparked a resurgence of interest in fossil fuels in countries like Africa, Small Island Developing States, and Southeast Asia, which are now looking to invest in oil, gas, and even coal (IEA, 2022).

In resource-rich countries such as Nigeria, Trinidad and Tobago, and Indonesia, the author's desk and field research showed that while short-term investments in oil and gas may make economic sense, relying on these resources makes economies vulnerable to long-term shocks (Alfaro-Pelico, 2000).

When advocating for a balanced approach, it is essential to go beyond comparing the costs of energy technologies like the levelized cost of electricity between renewables and fossil fuels. Instead, it's important to consider the broader benefits that clean energy offers, including job creation, a just transition, and collaborative innovation. These factors help address the critical issue of workforce development which both NWHRM and DREI models briefly consider.

7.2.1 Job Creation – Developing the Renewable Energy Workforce

Studies showed that investing in renewable energy and energy efficiency generates more jobs compared to oil and gas. For instance, a 2017 study by the Political Economy Research Institute found that every $1 million spent on renewable energy creates 7.49 full-time equivalent (FTE) jobs, compared to just 2.65 jobs generated by fossil fuels (Garret-Peltier, 2017). A review of fiscal recovery packages in 2020 also highlighted policies that can create social, economic, and environmental benefits, such as clean infrastructure and energy research in G20 countries (Hepburn et al., 2020).

As nations in the Global South seek economic growth with a lower carbon footprint than OECD countries, this data supports sustainable development. RMI's Energy Transition Academy (ETA) addresses the critical challenge of workforce development by training professionals to build future sustainable energy infrastructure. This program is already working in SIDS, with expansion potential across over 20 countries in Africa.

According to the International Renewable Energy Agency (IRENA and ILO, 2021), Nigeria's Solar Power Naija project aims to create 250,000 jobs by delivering solar home systems and mini-grid connections to rural households. Ethiopia's renewable energy deployment in sectors like horticulture and dairy can add 190,000 jobs while increasing production efficiency. Previous RMI analyses supported these findings, showing how electrifying agriculture in Nigeria and Ethiopia can drive economic growth (Santana, et al., 2020 and 2021).

7.2.2 Just Transition – Empowering Women and the Youth

The energy transition offers opportunities for climate justice and inclusivity, not just job creation. Women, who make up over a third of the global clean energy workforce compared to 20% in the oil and gas sector, stand to benefit. Research points to better gender outcomes in renewable energy, and IRENA estimates that in a Paris-aligned scenario, 60 million new jobs by 2050 will require only primary or secondary education, providing opportunities for a broader population (IRENA and ILO, 2021).

In Caribbean nations, women have been at the forefront of the energy transition. For example, indigenous Mayan women in Belize became solar engineers and installed over 100 solar systems in rural communities. The Women in Renewable Energy (WIRE) Network, consisting of around 600 women leaders, has facilitated the rapid expansion of gender-equal energy projects through mentorship and awareness programs.

In conclusion, the author research supported a narrative of co-benefits, rather than trade-offs, reinforcing the idea that reducing greenhouse gas emissions does not have to come at the expense of socio-economic development. Instead, it offers co-benefits, including stronger resilience to climate shocks in EMDEs.

7.2.3 Joint Innovation – Strengthening Local Content

While the energy sector has traditionally emphasized local content, fossil fuel industries have struggled to build value chains in countries like Nigeria. Renewable energy technologies, such as solar and wind, offer greater potential for local job creation due to lower certification and specialization requirements. In contrast, oil and gas investments often result in expatriate employment and foreign business practices, with long-term consequences for local economies.

Southeast Asian countries like Vietnam, a leader in solar photovoltaic (PV) job creation, demonstrate how developing economies can lead in technology deployment and manage their transition away from fossil fuels. Vietnam's solar PV sector generated 4 million jobs in 2020, providing a model for others to follow (IRENA and ILO, 2021).

The author advocates for local ownership of energy transitions, aligning with domestic priorities and leveraging local knowledge (Alfaro-Pelico, 2022a). This approach, combined with scientific data, can enhance stakeholder engagement, increase employment, and strengthen local procurement efforts.

7.3 Expansion of Public Acceptability Dimensions

Achieving a just energy transition requires a broader consideration of public acceptability dimensions of long-term emission scenarios beyond their technical, financial and environmental implications. After a decade of thought leadership in the now more widely accepted people-centric approach toward decarbonization (Alfaro-Pelico, 2022), IRENA research shows the need to dive deeper on acceptability elements of the energy transition (IRENA and ILO, 2024).

It goes beyond human capital dimensions linked to job creation, and take into account experiences in EMDEs and OECD countries, such as members the Group of Twenty (G20) that represent the bulk of the world's current carbon footprint and global investment in renewable energy (IRENA, 2024). Yet the uneven distribution of RE deployment across countries represent gaps in access and affordability – with 685 million people without electricity, mostly in Africa (ibid.).

As emerging markets and developing economies seek to pursue their development ambitions, key questions around justice dimensions of the energy transition have emerged. They are often associated to trade-offs between fossil-fuelled and renewables-based growth that case studies in preceding sections show. This dilemma calls for alignment on a common understanding of the assumed notions of justice, and their divergent relevance across EMDEs that engage in global climate negotiations with diverse stances, as underscored in regions such as Africa and Small Island Development States (SIDS) with a heterogeneous position (Alfaro-Pelico, 2010, 2012).

These justice notions need to be translated into decarbonization outcomes that are in line with updated Nationally Determined Contributions (NDCs) after COP-21 in Paris, all the way to the Global Stock-Take (GST) and UAE Consensus reached at COP-28 in Dubai. Indeed, translating these concepts and other such as "inclusive", "fair", "orderly" or "equitable" expectations of the energy transition has become urgent, and so is the need to level-set expectations ahead of COP-29 in Baku, and manage climate frustrations as intended ahead of COP-27 in Sharm El-Sheikh (Lázaro Touza and Alfaro-Pelico, 2022).

Terms such as equity and equality, justice and inclusion are used often interchangeably, but they do not mean the same to different countries, regions and people within them. These clarifications would also help inform how COP parties and non-state actors approach the climate negotiations and pledge critical support to achieving a just and inclusive energy transition. This clarity would help inform G20 countries in their planning and financing of emission scenarios, with social, economic and environmental outcomes in mind.

The aim would be ensuring an even distribution of resources associated with these outcomes and ease the burden of the low carbon future for people less equipped and more vulnerable to its negative impacts.

In this regard, this section seeks to broaden the understanding of public acceptability dimensions. They would need to be at the core of all efforts to mitigate the effects of the growing social tension, economic exclusion and environmental degradation across the G20, and beyond. Ignoring these risks have shown increased political polarization worldwide, while addressing them would be a step ahead in realizing promises beyond green jobs (Alfaro-Pelico, Raul et al., 2023). Public acceptability would need to be rooted in meaningful engagement and empowerment for the energy transition to be just.

7.3.1 Introduction to Just Energy Transitions

Research showed that the current energy system is not just and needs to be radically and fundamentally transformed to avoid catastrophic climate impacts (IPCC, 2019, 2022a, 2022b, 2023a). If the system is to remain sustainable, renewable energy will be critical to mitigate climate change and adapt to its negative impacts on people and the planet (IPCC, 2023a; IRENA, 2023d).

Renewable energy offers health and nature solutions, such as decreased air pollution; it holds the promise of jobs and livelihoods for millions of people lacking energy access, the creation of local value and contribution to industrial growth, reduction of fossil fuel import dependence, thereby enhancing energy security and strengthening resilience to external climate shocks (IRENA, 2019a, 2020d, 2023d).

IRENA research also showed that these promises will not be automatically realized for all, especially those left behind by fossil-fueled and renewables-based systems. Their transition either way will create misalignments requiring structural transformations (IRENA, 2022a). Deep policy interventions are needed to address the social, economic and environmental implications of the energy transition, and realistically achieve the justice and inclusion outcomes that different types of countries ambition.

Chosen energy technologies, finance instruments, investment location and size, infrastructure deployment and ownership, amongst other key decisions carry inherent justice implications. Questions about how the transition unfolds, who decides on which pathways to take, who is consulted and whose values and priorities prevail will shape the costs and benefits of fossil fuel depletion and renewable energy acceleration. With the limited carbon budget available, a particular focus also has to be on what energy is used for, and what kinds of modes of life can be sustained, to keep the planet livable for present and future generations.

Additional questions arise around the pace and scale of the desired energy system transformation, with inherent justice considerations. A transition that is too slow to address climate tipping points is unjust both to present and future generations withstanding the resulting shocks. Too fast a transition is expectedly more disruptive and brings much quicker to the fore its difficult trade-offs. Notwithstanding these dilemmas, the Intergovernmental Panel on Climate Change notes that "outcomes seen as equitable can lead to more effective cooperation" (IPCC, 2014). The absence of equity instead might explain backlash to climate policies, such as the yellow vest protests in France, or legal challenges to large-scale renewable energy projects, such as by the Sami people in Norway. They highlight the importance of securing buy-in (Hofverberg, Elin, 2021; WWF, 2021). Therefore, the energy transition should consider the needs and aspiration of people, individuals and communities, if it is to happen.

7.3.2 Definition of Just Energy Transitions

Despite the aspiration that decarbonization pathways consider justice (among other values such as inclusion, equity, equality or fairness), there is no universal definition of a just and inclusive energy transition. The widespread of use of these terms do not make them any clearer, hence the need to clarify the concepts. To this end, this section provides background on notions of just transitions from global fora and highlights the challenges and opportunities to define them in the energy space. For ease of reference, the sections only mention "just transition", with implicit consideration of inclusion, fairness or equity.

7.3.2.1 Origins and Evolution of Just Transitions

The concept of what would eventually come to be called "just transition" was conceived by labour union members and activists. Emerging in the United States in the 1970s and the 1980s, in its earliest conception it was primarily concerned with ensuring the occupational safety and health of workers in the fossil fuel, chemical and atomic industries.

Then discussions and advocacy also centred around developing alternative economic models rooted in social and environmental justice (Morena et al., 2019). References to "just transition" increasingly entered mainstream international and national climate-related debates in the 2010s. A significant milestone was the publication of the Guidelines for A just Transition Towards Environmentally Sustainable Economies and Societies for All, developed by the ILO over two years in collaboration with experts from trade unions, business sectors and governments.

The guidelines focused on workers and strongly rooted in the decent work agenda, which encompasses social dialogue, social protection, rights at work and employment. While jobs-centric, the vision setting the framework for the guidelines also recognises broader goals. These include poverty eradication, social inclusion, economic growth and environmental sustainability, with the needs of future generations too in mind. It also stressed the importance of introducing more energy and resource efficient practices. (ILO, 2015).

Due to advocacy by the International Trade Union Confederation and others, including the development and environment communities, just transition picked up momentum and was included as a policy goal in the 2015 Paris Agreement (Morena et al., 2019). The Paris Agreement refers specifically to "just transition of the workforce" and subsequent decisions of the Conferences of the Party (COP) expanded this meaning. The Glasgow Climate Pact adopted in 2021 called parties to 'transition towards low-emission energy systems [...] while providing targeted support to the poorest and most vulnerable in line with national circumstances and recognising the need for support towards a just transition' (UNFCCC, 2021).

The Just Transition Work Programme adopted at COP two years later noted that just transition "encompasses pathways that include energy, socio-economic, workforce and other dimensions". It linked it to poverty eradication and sustainable development, inclusive and participatory approaches along with the need to create decent work and quality jobs, including through social dialogue, social protection and the recognition of labour rights (UNFCCC, 2023). Just transition was also referenced in G7 and G20 communiques, and a growing number of countries sought to advance just transition efforts through national policy. For instance, task forces and commissions were created in Canada, Germany, Scotland, Australia, Ireland, New Zealand, US (Appalachia), South Africa, and the EU (Heffron, 2021). In a growing number of cases, this led to allocating initial funding and setting timelines for the phase out of fossil fuels.

The UAE Consensus adopted at COP-28 in 2023 marked the beginning of explicit commitments to a fossil fuel phase-out agenda, as it held the First Ministerial Meeting of the Just Transition Work Programme. The discussion acknowledged that different actors were championing different visions and solutions of a just energy transition, including approaches that sought to maintain the status quo, and rely heavily or exclusively on private sector and profit-oriented responses. Others included further-ranging managerial reforms that include some legislative action. Additional views advocated for deep structural measures that are more ambitious and entail economy-wide institutional transformations. Finally, other approaches advocated for a different relationship between societies and nature, as the push for green deals at national, regional and global levels has shown.

7.3.2.2 Challenges of Defining Just Energy Transitions

The difficulties in arriving at a common definition for just transitions, mirror those of defining justice. While it is often instinctively assumed that there is shared understanding of justice, it means very different things to different people – without exception in the context of the energy transition. Despite perceptions that justice applies universally and is objective, justice is ultimately a human construct and its perception subjective.

Psychological studies have found that notions of justice are shaped not only by prevailing cultural norms, but also by factors such as experiences, information, social contexts and emotions. This also applies to how individuals and groups resolve conflicting values and prioritize values such as “expedience, practicality and financial growth” (Baasch, 2023).

These tensions and differences are also apparent in the different visions for just energy transition. While there is broad agreement on the need for justice, the way justice is construed reflect different values, economic and social perspectives and priorities and references to “just (energy) transition” can refer to fundamentally different understandings of what justice looks like and what actions are needed as highlighted later.

The absence of a “shared interpretation of the right or good” makes a universal justice definition elusive a challenge that extends to defining the meaning of just energy transition. (Hall, 2013). While there is no shortage of calls for just energy transitions, what this specifically entails is often ill-defined and ambiguous. Building a shared understanding requires recognising the different values and philosophy that people and communities hold. Without specifying the moral underpinnings that are to apply to claims for justice, it can also be difficult to examine and debate the near and long-term consequences of a given ethical outlook for people and planet. (Dirth et al., 2020).

Lack of a shared understanding has also led to an indiscriminate use of the just energy transition as a buzzword, with the interchangeable use of justice, equity, fairness and inclusion adding to terminological difficulties and obfuscation.

As discussed below, just energy transition has at times been equated simply with an energy transition or also with energy transitions that enable development in national and international documents. Given the appeal and current popularity of the concept, it frequently occurs that the term just (energy) transition is used to refer to related concepts. One common occurrence is that the word "just" is simply added to energy transition. Energy transitions generally denote the process of switching from a prevailing set of energy resources to a different one.

In the current context, this includes efforts to shift from fossil-fuel to renewables-based energy systems. However, while renewable energy holds immense advantages over fossil-fuels due to climate, social, economic and geopolitical reasons outlined above, renewable energy technologies and the transitions to them are not free of their own impact. The same holds true for other solutions and technologies discussed to remove energy-related emissions from the atmosphere. Just (energy) transitions are also often mentioned in relation to sustainable development. Sustainable development has been defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987).

On the international level, the most recent universal expression is through the UN 2030 Agenda which encompasses 17 Sustainable Development Goals (SDGs), which cover goals ranging from poverty eradication, food and water security, sustainable energy access, climate action to economic growth and decent job creation (UN, 2015). While deeply intertwined and overlapping, just energy transition and sustainable development have their own histories, scope and specific challenges and keeping this in mind when referencing is useful.

Similarly, just energy transition calls on the international plane use a mix of terminologies such as justice, equity, fairness and inclusion without clearly explaining the distinction between concepts. Box 5.2 provides an overview of the different understandings of these terms and how they can be distinguished. The discussions around just energy transitions also involve calls for such transitions to be equitable, fair and/or inclusive (see e.g. (UN, 2023)).

References to these concepts are linked to international climate negotiations, where the terms are widely used and deeply contested. Their interpretation is perpetually debated in the communities that use them. This is also reflective of broader tendencies in international environmental law as well as climate and energy politics to use aspirational concepts without defining their meaning or consistent use of terms (Carlarne and Colavecchio, 2019). To deepen the understanding of the use and contestations around these concepts, the below is a brief overview of the use of these terms.

Looking at *justice*, a wide range of different forms of justice are referred to ranging from climate justice to environmental justice, ecological justice, distributive/procedural/restorative justice, transitional justice, intergenerational justice (Wilton Park, 2022). Notably, the term justice is not referenced in any international climate agreement or decision until the UNFCCC COP21 in 2015, the year in which the Paris Agreement was adopted and which explicitly calls for "climate justice" (UNFCCC, 2015). The inclusion of the concept was owed to the social movement that had rallied behind the concept over the preceding decades.

Prior to this, references to justice had been minimised to avoid engaging in complex questions of moral responsibility and legal liability. Intrinsically justice is linked to the administration of laws including deciding on punishment and rewards in the context of conflicting claims. Notions such as accountability and restoration for injustices are elements that distinguish justice from equity and fairness. This also underpins why states have sought to avoid references to justice during particularly during climate negotiations (Carlarne et al., 2019).

Inclusion is not explicitly a core principle of international climate and environmental law. It is still relevant to a number of principles including justice and equity, which aim to distribute burdens and opportunities fairly, with particular concern to marginalized and vulnerable populations – as depicted (below), equity has inherent justice and inclusion considerations compared to equality. Inclusion gained relevance because traditionally the just transition discourse initially focused on (male) fossil fuel workers.

Subsequent discussions sought to broaden the scope as discussed to also consider the needs of the communities and opportunities and burdens more widely, including marginalised communities such as in rural areas that struggle with electricity access, women, youth, and Indigenous Peoples. Inclusion in this context often refers not only to these groups as benefit holders, but their actual inclusion in decision-making processes to do with the energy transition, given their historic absence from many decisions that impact their livelihoods.

While *Equity* is a long-standing principle in climate negotiations, it is often misunderstood with *Equality*, but the latter would lead to injust and exclusive outcomes. Equity is rooted in the recognition that countries have differently contributed to climate change and have different capacities and needs. "Common but differentiated responsibility" (CBDR) is equity's twin principle even though neither principle has an agreed upon definition.

Equity alongside justice and inclusion go beyond CBDR by covering the 'specific needs and special circumstances of developing countries', 'the importance of precautionary measures', 'cost-effectiveness' and the right to 'sustainable development' but also intra and intergenerational equity (Carlarne et al., 2019). These clarifications provide an opportunity to acknowledge the different past and current experiences between countries, groups and people to understand such tensions as the right to pursuing fossil-fuel powered development.

They are imperative in preventing the devastating impacts of climate change for current and future generations, which require collective action. For instance, reviewing statements by the largest oil and gas companies, seven out of twelve companied surveyed refer to a just transition in their programmes. Yet, this does not translate into significant investments in renewable energy. Over the last decade, fairness has emerged as an additional normative tool to assess state behaviour and advance discussions on collective climate action. It is reflective of a paradigm shift in the climate sphere, from the top-down structure of the Kyoto Protocol (allocating responsibility for action based on UN-designated divisions of developed and developing countries), to the more bottom up approach of the Protocol's successor the Paris Agreement (allocating responsibility to all parties).

Under the Paris Agreement, countries are asked to describe how the Nationally Determined Contribution they agreed to submit is a "fair and ambitious, in light of national circumstances" (UNFCCC, 2015). The challenges of understanding the notions of justice and inclusion are not specific to the energy transition.

7.3.2.3 Opportunities for Addressing Just Transitions

Research shows a renewables-based energy transition holds the potential of positive transformation of individuals and communities when empowered and given a voice or stake in their future (IRENA, 2024). Barriers to deployment of renewable energy need to also consider ways to unlock strong public support, or building social acceptance, key to consider market, socio-political and community elements of such acceptance underpinning support and trust for renewable energy (Rolf Wüstenhagen et al., 2007); thus, acceptance requires attention to be drawn to its different dimensions, as depicted in *Figure 45* (below):

Figure 45: Social Acceptance of Renewable Energy

Source: Rolf Wüstenhagen et al. (2017)

These acceptance elements are interconnected and require the identification of the justice and inclusion gaps discussed in the next section. An essential condition to fill those gaps is the establishment of trust among stakeholders. It influences public acceptance in all aspects, including communicating with a wide range of local stakeholders from the initial planning stages of the project, giving due consideration to the unique local context when selecting technology, location and scale, and emphasizing investor support.

Based on the author field research to ensure broader public acceptability, governments should aim for a more systematic approach to assess how energy projects can maximise value to the communities in which they operate.

Community-centred and participatory approaches witnessed or supported in the author's renewable energy project portfolio proved to address the unique needs, values, and aspirations of diverse social groups, and incorporated their views in decision-making. It helped to tap into social opportunities of switching to renewable energy and accelerating the decarbonisation of the energy sector.

Transition in the energy sector are still mostly seen through a technological lens, focussing on infrastructure innovation and shifts in supply. Often, the social dimension of the energy transition is limited to a question whether communities would accept renewable energy developments. This perspective overlooks the need to generating broad agency in terms of the ability to act and influence decisions, across all countries. For instance, Denmark accelerated the development of wind power meeting over half of its electricity demand through policies that enabled citizens to have a financial stake in these projects. The Promotion of Renewable Energy Act entered into force in 2009 requiring renewable projects to offer at least 20% ownership to local residents (per the Danish Ministry of Climate, Energy and Supply, 2008).
These social sustainability approaches require cooperation and public support for an intervention, preserving specific societal values, such as intra-/inter-generational equity and human rights. A social performance approach referred to direct and positive social impacts on the well-being of communities during the development and implementation of energy projects and the use of locally generated energy, in monetary and non-monetary ways. It required social, environmental, and economic dimensions to act as support systems that facilitate well-being and opportunities for individuals or communities. Broader ownership maximised social opportunities and prevented conflicts, and highlighted socioeconomic co-benefits, which allowed to simultaneously meet several objectives such as creating employment and health cost savings while reducing greenhouse gas emissions (Alfaro-Pelico, 2022; Helgenberger et al., 2019).

While climate debates centred discussion on fairly distributing socio-economic costs within and across generations and regions, the co-benefits discourse changes the narrative "from burden-sharing to opportunity-sharing" (Helgenberger and Jänicke, 2017). Job numbers or health cost savings have been examined in numerous studies, which facilitate connection to specific political agendas and socioeconomic interests (IASS and TERI, 2019; IASS et al., 2020; IRENA and ILO, 2023a). In line with the co-benefits narrative, the social performance approach calls for quantifiable and policy-directed assessments to reconcile socioeconomic priorities with climate action, thereby requiring active community participation (Mbungu and Helgenberger, 2021). The social performance approach provides tools to compare how different energy options (e.g., a renewable wind park, decentralised energy services, such as solar mini-grids, or a coal mining site) perform for local communities allowing to identify the option that maximises positive outcomes and reflects their aspirations for a good life. Steps that facilitate the identification of justice and inclusion gaps, including lack of acceptance, fair representation, include:

1. Defining the regional scope (context / community) and resources of a social performance assessment.

2. Identifying stakeholder groups and individuals to be consulted in view of representation of important interests, needs or conflicts, and social / economic /transformative role on the community.

3. Creating a list of mutually agreed objectives following inputs from all stakeholders.

4. Specifying an agreed list of indicators to track the objectives.

5. Performing a participatory assessment of the indicators.

6. Compiling and communicating the results in a scientifically sound and accessible language.

7. Co-creating enabling policy options to increase the social performance of ongoing / planned energy projects.

These steps point to the need to understand the different dimensions of justice and social acceptance. The next section explores these justice dimensions and looks at some initiatives taking place across G20 countries and regions, to help expand the understanding of public acceptability considerations.

7.3.3 Notion of Justice in Energy Transitions

Justice and inclusion only acquire meaning within specific contexts, such as those unfolding in the energy transition. It is not possible to identify gaps in the abstract, and so context will help develop suitable approaches for relevant stakeholders sensitive to their particular environment. For instance, the lived experiences and priorities of energy workers and communities in developing countries are markedly different from those in advanced economies, despite potential parallels and similarities. Injustice and exclusion is pervasive in the current fossil-fuelled system and will be perpetuated by any system (renewables-based or other) that replaces it unless they are understood and effectively tackled in the context it is meant to be addressed.

How just and inclusive the energy transition itself hinges on choices to address related gaps made by policymakers, businesses and civil society. Examining key dimensions of just transitions (with focus on justice as common term used in the climate negotiations, but extensive to other terms explained in the previous section), can help to crystallise its concrete meaning and translate the concept into policies and actions. Firstly, it is important to achieve a fair distribution of benefits and burdens (distributive justice). Secondly, it is necessary to acknowledge and address existing biases and vulnerabilities (recognition justice). Thirdly, it is crucial to consider ways to repair prior harm (restorative justice). Finally, desirable outcomes depend on decision-making processes and broad participation by those affected the most (procedural justice). These elements are considered in more detail next, to help identify often ignored just transition gaps when looking at long-term energy scenarios. It also discusses justice dimensions linked the locations (across geographies), institutions (within power structures) and generations (over time), with implications for policymakers when addressing these gaps in the medium- and short-term.

7.3.3.1 Distributive Justice – Fair Distribution

Already today, the social and economic benefits and costs in existing energy systems are not borne equally (IRENA, 2023d). Designing just policies requires taking into account the full range of distributional consequences of energy transition processes, climate imperatives and development needs, alongside existing and expected inequalities. Interventions need to consider both injustices of the current energy system, as well as those that might arise during the transition.

- *Ownership*: Ownership and profits of the resources underpinning the current fossil-fuel dominated energy system is highly concentrated in the hands of a few large companies, energy exporting companies and financial institutions (Biswas et al., 2022). Who controls and owns energy projects and infrastructure, as well as how revenues and benefits are distributed has justice implications.

For instance, while the private sector is expected to play a key role in the energy transition, an outsized focus on private profit maximisation, excessive concentration of ownership in the hand of a few companies, and commodification can run counter to the spirit of ensuring benefits are equitably distributed.

Studies show that community ownership "bring more capital into local economies and can strengthen communities in terms of empowerment, skills development and local regeneration"; as well as "reduce usual community concerns by working to improve the distribution of costs and benefits (van der Waal, 2020)." This relationship is not automatic, however. Hence, transition-related projects that are meant to enhance rather than reduce social justice may need to include specific social objectives such as benefiting communities in which they are being built.

- *Financing*: How and where the energy transition is funded matters. Renewable energy costs are competitive in a growing number of contexts (IRENA, 2023e). There question of who pays for new infrastructure and technology (e.g., power grids, system flexibility, energy efficiency), measures to ensure universal access to energy, and adapt to and mitigate climate change.

In this context, the effective use limited public resources will be critical for the transition (IRENA and CPI, 2023). Yet, support for fossil fuels is deeply ingrained in the current system. While precise estimates vary, financial support for fossil fuels compared with renewable energy is evident, and conventional measures of subsidies likely underestimate the contrast. Fossil fuel industries also continue to receive by far more finance than renewable energy investments by international and domestic public finance from G20 export credit agencies, development finance institutions, and major multilateral development banks (Indira Urazova et al., 2023).

For instance, the Public Finance for Energy Database shows that over the five-year period of 2018 to 2022, fossil fuels received over USD 272 billion in of public finance in the G20 countries, compared with USD 158,6 billion for "clean" energy, with four countries accounting for (OCI, 2022). This further highlights the need for dedicated transition-finance. The uneven distribution of renewables funding and the lack of access to affordable financing also poses challenges, as an additional justice dimension across geographies later.

- *Availability and affordability*: A distributive lens also requires considering availability and affordability of energy services as a pre-condition for meaningful development and key justice element justice. 685 million people continue to lack even basic access to electricity (80% in Sub-Saharan Africa), while 2.3 billion people reliant on harmful cooking (IEA et al., 2024). Inequities also exist in industrialised countries, where the poor can be similarly forced into trade-offs between energy and other basic services (food, nutrition, health, education=.

Across countries low-income and marginalized communities tend to incur higher costs and have to pay a larger share of their income to cover their energy costs. Inadequate or substandard energy equipment and infrastructures coupled with limited financial resources for improvements further exacerbate the situation (Biswas et al., 2022). The poorest 10% of humanity are estimated to account for less than 2% of total final energy consumption, while the top 10% consume nearly 40% (Oswald et al., 2020). Volatile energy prices common in the existing system tend to affect welfare in import-dependent countries.

They lead to public expenditure spikes in countries that subsidise energy products, capturing money that could else be invested in pro-poor sectors, and causing instability. For example, “75 million people who had recently gained access to modern energy are at risk of losing it due to affordability issues”, and higher costs following the war in the Ukraine meant 31 million of households were unable to adequately heat their homes in 2021 (IEA et al., 2023; Igawa and Managi, 2022). Depending on policy choices, the transition to cost-competitive renewables based energy systems with expanded electricity access can provide greater price stability and lower prices and greater geopolitical stability. (IRENA, 2024d).

Energy poverty is situated in the wider context of economic inequality. On the global level, the top 10% capture 76% of all wealth. The poorest half strikingly own less than 2% of global wealth. Similarly, the richest 10% of the population earn 52% of global income, while the bottom half merely earn half. Inequalities within countries are also on the rise (Chancel et al., 2022). Growing economic disparities exacerbates poverty, including energy poverty (Galvin, 2019). Affordability of energy services therefore needs to be seen in the wider socio-economic context of individuals and groups.

- *Social and economic impacts*: The transition brings significant socio-economic benefits, but as with any major change also has disruptive impacts that can adversely affect different groups. Job losses in the fossil fuel sector are widely expected to be offset by gains in energy transition related sectors including renewables, energy efficiency, power grids and flexibility, vehicle charging infrastructure and hydrogen (IRENA, 2023d).

Job losses are at the heart of the original understanding of just energy transition and examining and addressing impacts on workers who stand to lose their livelihoods is critical. Attention also needs to be paid to ensuring that new opportunities created are also open to historically marginalized or discriminated groups. Economy wide prevalence of precarious jobs is also affecting the energy sector (source), and attention is needed to ensure jobs created are decent per ILO’s Decent Work Agenda.

The energy transition can also underpin sustainable development and economic objectives, benefitting national and regional economies. Beyond job creation, this includes creating investment opportunities and the creation of new industries and markets and export opportunities.

IRENA estimates that a pathway aligned with 1.5°C objective would lead to an annual average increase in GDP between 1.5% and 2.6% depending on the policies chosen. Economic benefit may also be derived through a number of cost savings. Lower energy costs for business and households can free up money for other forms of spending, thereby stimulating economic activities. Reduced dependence on fossil fuel imports can improve energy security and reduce vulnerability to volatile energy prices, which leads to more stable energy costs for businesses and consumers. A sustainable energy system also translates into reducing the economic burden associated with addressing significant pollution-related expenses and environmental restoration associated with fossil fuel-based energy production. Different social groups, countries and regions will benefit differently as discussed below (IRENA, 2023d)

- *Benefits*: The energy transition also entails the promise of vast benefits. (IRENA, 2023d) Yet questions remain who will reap the benefits spanning opportunities to create value locally, take part in the jobs and businesses as well as enjoy improved livelihoods and welfare. This applies geographically within and across regions as described in the section on justice across geographies. But also socially in terms of gender, ethnicity, income or class, with for instance the poorest segments of the population or women more frequently excluded from benefitting from renewable energy opportunities including subsidy programmes. (Galvin, 2019; IRENA, 2019b; Johnson et al., 2020).

- *Environmental impacts and externalities*: No infrastructure development is without environmental impacts, and so are energy transition investments. This includes the entire supply chain, including the impact of mining for transition-minerals and materials, value-creation from raw materials, as well as the deployment of renewable energy (Agrawal et al., 2023a).

Indigenous Peoples are among the most hard-hit people from the environmental impacts of renewable energy, often repeating long histories of negative impacts by fossil fuels and other extractive industries (Indigenous Peoples Majors Group for Sustainable Development, 2019). Researchers have observed that especially consumers in energy importing countries exhibit a degree of "consumer blindness" in that they are oblivious to where and under which frequently damaging conditions energy they take for granted is being produced (Healy et al., 2019). One critical question of justice in the context of the energy transition includes who bears the cost of the externalities from environmental impacts across the supply chain, and life cycle of clean energy projects.

Historical and current responsibility, emissions and growth: Both historically and currently, there are staggering differences in emissions which contribute to climate change – most originating in the energy sector. The World Inequality Report 2022 shows that "the top 10% of emitters are responsible for close to 50% of all emissions, while the bottom 50% produce 12% of the total". Emissions referenced also include emissions embedded in imported goods and services (Chancel et al., 2022). Responsibility for emissions is also highly unequal between income groups. A global survey on energy inequality among 86 countries founds that top 10% of income earners consume approximately 20 times more energy than the bottom 10% - therefore also contributing proportionally more to emissions (Oswald et al., 2020). Within the EU, "while the top 1 per cent of emitters had a carbon footprint of 43.1 tonnes CO2 per capita in a year, that of the bottom 50 per cent of emitters was only 4 tonnes." (Ivanova and Wood, 2020).

This level of inequality also works across regions and income groups congruently; regional disparities are also notable as "poorest 20% of the UK's population consumes more than five times the energy per capita of the bottom 84% in India" (Oswald et al., 2020). These considerations have large implications on the big questions. Who should reduce energy-related emissions most, and who is meant to pay to emissions reductions? It is particularly relevant when considering people that are already in hardship (such as low-income countries and income groups).

7.3.3.2 Recognition Justice – Vulnerabilities and Bias

Related to distributional and procedural justice, recognition justice seeks to shine a light on the fact that certain groups are or may suffer particularly from inequalities in the energy system – as well as its adverse impacts, including climate change. It builds on the notion that all people deserve fair treatment and an opportunity to participate in processes as well benefit from the energy transition, regardless of their social, economic, ethnic, racial and cultural background or their gender.

A key question in the context of recognition justice is “a just energy transition for whom”? It asks to interrogate whose interests and values are recognised in the transition and emphasises the need to protect equal rights for all. It also emphasises and recognises particular vulnerabilities, including of those that are poor, ill, disabled, unemployed or otherwise disadvantaged and marginalised as well as their heterogenous energy needs.

As those marginalised are often systematically constrained in their capabilities to exercise and defend their rights, a separate lens is warranted. By extension a full understanding, and respect for, the circumstances of energy-related deprivation or adverse impacts can help to unveil and address deeper structural causes and external factors contributing to energy hardship and wider inequalities. Recognition justice highlights the importance of acknowledging the identities, lived experiences and rights of marginalised and historically oppressed groups and co-developing appropriate solutions.

Indigenous peoples and other marginalised groups have particularly suffered from injustices related to energy development, including displacement, loss of land, and health impacts (Sovacool et al., 2016). Studies have also shown that energy poverty disproportionately affects people living with disability (Snell et al, 2015). Similarly, people experience injustices due to their gender, income and race but also their age, religion, or location (Sovacool et al., 2020). In different cultural contexts, energy poverty might also be stigmatized. This is particular in countries where high levels of energy consumption are the norm.

Lacking recognition of issues around affordability, adverse burdens and broader exclusion from energy transition benefits carry significant policy implication as they impact whether such issues are acknowledged and how such issues are addressed. (Bouzarovski and Simcock, 2017). Recognition is also critical for energy modelling, which is often dominated by cost-optimizing narratives that tend to not account for structural inequalities, the needs of marginalized groups both in the parameters that underpin the model, as well as in the consultation process (Rubiano Rivadeneira and Carton, 2022).

7.3.3.3 Procedural justice – Processes and Participation

Justice is not only about how benefits and burdens are distributed, but also about the process through which decisions about energy transitions are made. Procedural justice stresses the importance of having those impacted by decisions included to be directly or indirectly represented, a key principle also underlying democracy.

Research shows that more inclusive processes tend to lead to improved decision making (source) and that the outcomes of processes considered to be fair are more easily accepted by the public (Bal et al., 2023). A key question under procedural justice is "What procedures, laws, and institutions do we have in place to ensure most vulnerable groups are protected from transition-related costs they cannot reasonably bear?" as well as to provide a fair process to consider how to negotiate the trade-offs inherent in the energy transition.

Procedural justice emphasises the importance of due process, meaningful participation as well as full information disclosure by governments and industry and appropriate engagement and redress mechanisms both at the national and international level. This lens can also be used to understand and respond to unequal representation and influence in a wide range of institutions including local, national and international governmental institutions as well as business and civil society organizations from advocacy groups to labour union representations.

Public participation and deliberation have been traditionally weak in national energy policies and strategies in many countries due to geostrategic considerations including available energy resources and reserves (Burke and Stephens, 2018; Newell et al., 2021).There has also been a tendency to use public consultations to validate prior choices and pre-established decisions, rather than inform the decision-making process to begin with.

A growing number of case studies shows that communities directly impacted by energy and infrastructure projects have been excluded from decision-making processes, including in instances where formal and compulsory environmental impact assessments were required (Agrawal et al., 2023b; Ciplet, 2021). Evidence on participatory processes also indicates that groups with specific privileges, such as high wealth, education, or social standing are able or willing to engage actively. (Scherhaufer, 2021).

Social groups like people from rural areas, indigenous peoples, senior citizens, women, low income groups or people with disabilities are often left out, they are not recognised or the modalities of engagements do not allow for their participation (Suboticki et al., 2023). Ensuring more open and meaningful processes that go beyond provision of information will be critical, particularly given the access of fossil fuel interests and their embeddedness and influence on energy decisions, to the detriment of citizens (Newell, 2021; Scherhaufer, 2021).

As with conventional energy projects, many different risks are associated with renewable energy deployment that can negatively impact local communities and, in particular Indigenous Peoples. These impacts include land acquisition without Indigenous Peoples' free, prior and informed consent or meaningful engagement; physical and/or economic displacement; and, loss of culture and traditions. There are also impacts to community cohesion and identity of Indigenous Peoples, and threats to community health and safety, in addition to other environmental impacts. Autonomy and decision-making powers are at the heart of social license to operate.

While most jurisdictions require consultations, these are all too often done primarily pro forma without meaningful engagement (Owen et al., 2022; Vanclay, 2020). Indigenous peoples and other land-connected peoples in particular face significant challenges in protecting their rights in land. (Owen et al., 2022).

Frameworks to tackle conflict of interests between politicians and fossil fuel (related) companies, their lobbyists and seconded personnel also need to be addressed (Newell et al., 2021). Challenges for procedural justice also include the limited influence in national policy decision-making and international negotiation processes of those negatively impacted by the energy transition.

Legal safeguards are also needed for both development financial institutions (DFIs) and foreign investors in developing countries (Agrawal et al., 2023c). This also concerns the voice and influence of developing countries in decision-making of such DFIs, and climate funds, which would enable countries realise their energy, economic and social goals. This is also reflected in the access to financial resources to participate in global negotiations. The UN Secretary General noted it in his remarks to the Group of 77 'Hold Developed States to Account for Climate Justice" (United Nations, 2024a).

Institutions and mandates: Governments, regulators, financing institutions and utilities often operate primarily concerned with issues of technical feasibility and reliability (Shelton and Eakin, 2022). Environmental impacts sometimes feature, but the way these impacts are assessed, and by who, differs significantly (Agrawal et al., 2023). Businesses operating in the energy sector, including in transition-related sectors, typically lack the mandate to guard issues related to social justice concerns, although many have standards on human rights and environmental sustainability.

Some public institutions also lack the authority, mandate, processes and/or expertise to evaluate wider social justice concerns. Many projects and policies are also implemented by government institutions that lack critical processes and capacity to monitor and assess outcomes on vulnerable populations or are disincentivised from doing so.

Diversity, equity and inclusion in decision-making and leadership: While the renewable energy sector is generally considered more diverse, equitable and inclusive than the fossil fuel sector, surveys indicate that in the solar and wind sector women hold, respectively, 30% and 13% of managerial responsibilities – this dips further to 13% and 8% respectively in senior management roles (IRENA, 2020e, 2022b). There is no data available on the level of participation of minority groups, including Indigenous Peoples in government or financial institutions.

7.3.3.4 Restorative justice – Prevention and Reparation

This dimension focuses on rectifying injustices in the energy sector, and repair the harm done to people and planet. The restorative mechanisms and programmes needed to address past and on-going harm from the energy transition cover aspects such as responsible decommissioning, and livelihood restoration plans as fossil fuels are phased out. They also need to mitigate negative impacts by utility-scale clean energy projects, such as land loss and resettlement. Literature on green jobs is increasingly covering these social and environmental interventions as economic opportunities to realize the just energy transition promise (Alfaro-Pelico, Raul et al., 2023).

The need of critical materials for the energy transition will also increasingly cover the impacts of mining activities (IRENA, 2023f). Beyond identifying responsibilities and liabilities, a focus on restorative justice can also help societies consider what injustices require attention, and how these may be prevented. Reviews of past experience show that the basic principle of the polluter pays is rarely followed. In many cases of end-of-life damanges from former industrial and mining sites, the private sector passes cost for restoration to the public sector (Atteridge and Strambo, 2020). This makes legal intervention essential, especially in the context of transition projects that are meant to contribute to sustainable energy and development. By centring on the need for restoration, whether energy activities cause irreversible damage or their reparation costs are prohibitive comes to the fore (Heffron and McCauley, 2017).

In the international context, this requires difficult but important discussions about historical and current responsibility for climate change, loss and damages, polluter obligations, as well as unequal capacities to advance the energy transition, which result from past and current systemic injustices. Restorative justice can also take the form of effective grievance and compensation mechanisms applied to new, non-fossil energy projects. This is particularly for utility-scale renewable energy projects, typically land-intensive, with potential lasting impacts on local livelihoods (Waters-Bayer and Tadicha Wario, 2022).

Resettlements are one of the most severe consequences of these projects, but also conservation and carbon market-related programmes. They require effective compensation mechanisms that reach beyond monetary value (Agrawal et al., 2023c; United Nations, 2019). Land development for renewable energy projects can also involve environmental impacts, and cause changes to animal and livestock habitats (Waters-Bayer and Tadicha Wario, 2022). Protests and lawsuits against projects (Agence France-Presse, 2021; Renkens, 2024; Stagner, 2024) highlight the need for effective initial consultation – with potential changes to projects and their siting – as well as compensation mechanisms and enforcement considering the value of land lost to its traditional inhabitants. It also needs greater national and international engagement to help implement remedy mechanisms for populations impacted negatively by transition projects enforceable irrespective of affected groups' financial means.

7.3.3.5 Other Justice Dimensions

The above dimensions of justice in the energy transition have focused on the fair distribution of its benefits and burdens, underlying processes and specific challenges for marginalised groups; and the mitigation of harm along the way. The needs and aspirations of all need to be at the centre of decision making. In addition to the emphasis on access to affordable, reliable, sustainable and modern energy for all, and protection from any negative impacts, the transition needs to be sufficiently rapid energy transition to avoid catastrophic climate shocks for current and future generations. Hence, other dimensions of justice acquire relevance in a spatial, institutional and generational context.

Justice across geographies

Energy transitions and associated justice considerations also have a location dimension. The starting point for energy transitions varies and will impact regions and communities both within countries and globally differently. This lens brings to the fore 'where' benefits and burdens are distributed through societies. It helps understand the unique place-based needs, priorities and disadvantages.

The text to date has provided an overview of disparities in terms of access, energy consumption and socio-economic impacts. Looking specifically at renewable deployment and associated benefits show uneven progress across regions. While renewable represented an unprecedented 83% of electricity generation capacity additions in 2022, immense disparities exist across regions. (IRENA, 2023g). Renewable jobs are also heavily concentrated. China alone accounts for an estimated 41% of the global jobs, followed by the EU (12%), Brazil (10%), and the US and India with 7% each. (IRENA and ILO, 2023b) Modelling of impacts of 1.5°C aligned energy transition pathways also shows that depending on policy and strategy choices on the global and national level this distribution is likely to persists. IRENA's modelling projects that Asia might hold 55% of global renewable energy jobs by 2050, followed by Europe at 14%, the Americas at 13% and Sub-Saharan Africa at 9%. (IRENA, 2023d)

Within countries, particular attention needs to be paid to low-income, rural and peripheral areas (Banerjee and Schuitema, 2023). Typically, urban centres have better infrastructure and access to energy and other services, tend to fare better with 98 percent people having basic access, compared to 85 percent in rural areas (IEA et al., 2023). Inequities also exist in infrastructure, such as EV charging stations in affluent and commercial districts. (Khan et al., 2022).

Decisions made in one place can adversely impact just and inclusive energy transition impacts in other geographies. Local mining of critical materials and the value that is created, for instance, are shaped by national and international decisions and systems. Spatial justice approaches can also reveal limitations of proposed solutions.

To reconcile the Global North's high energy use with the Paris Agreement targets, most scenarios rely heavily on bioenergy-based negative emissions technologies. This approach is risky, but it is also unjust. These scenarios tend to appropriate land in the Global South to maintain, and further increase, the Global North's energy privilege (Hickel)" For example, bioenergy with carbon capture and storage "(BECCS) will create competition for land among food producers, as more and more cropland will be dedicated to growing crops for fuel. In fact, it is estimated that rolling out BECCS at scale will require up to 3000 million hectares – around twice the amount of land that is currently already cultivated, globally."

The phase out of fossil fuels will particularly affect regions, countries and communities that depend on fossil fuel production. Especially countries in the Middle East and North Africa, but also in parts of North America, Eurasia, Southern Africa and Asia Pacific continue to rely economically on exporting oil, gas and coal. Most fossil fuel exporting dependent countries have tried to diversify their economies, with varying success. For instance, despite marked improvements in the GCC hydrocarbon revenues make up between 39% (UAE) and 89% (Kuwait) of public revenues. (IRENA, 2023h)

Justice across power structures and hierarchies

Energy-related injustices do not randomly occur, according to (Lee and Byrne, 2019). Recognising vulnerabilities, improving distribution and creating inclusive processes as part of the energy transition, may fail to provide a full understanding of systemic causes that may need to be addressed.

The energy sector is embedded within socio-economic systems that frequently reinforces and enshrine poverty and inequality in communities that lack the economic or political resources or power to change how these systems work and are systematically disadvantaged as described above.

The systems, institutions, policies and practices that enable and/or fail to address injustices also need to be scrutinised to gain an understanding on how to enact change and deliver just energy transitions. (Newell et al., 2021; Stevis and Felli, 2020).

Injustices can be linked to broader inequalities of in global and national orders (Symons and Friederich, 2022), and other researchers question whether the prevailing economic model can support just energy transitions (McCauley and Heffron, 2018).

Leaving aside short-term measures in response to the COVID-19 pandemic, austerity seems to remain the macroeconomic default option, liberalization the preferred instrument for inducing structural adjustments and debt the tool to drive development (UNCTAD, 2019) The international order has been particularly questioned as well. WTO's Trade-Related Intellectual Property Rights Regime is considered to impede the ability of those in need access to essential goods and services (Sokona et al., 2023) .

Access to affordable finance and technology remains elusive for most developing countries. Well-functioning markets, investments, trade and finance are critical, but it cannot be assumed that in and of themselves they will lead to just societies. As mentioned in the section on procedural justice imbalances also exist in multilateral negotiations and fora. For instance, in negotiation on climate mitigations high-carbon emitting nations have greater sway than those most vulnerable, including small island states (Van Bommel and Höffken, 2023).

Incumbents are often privileged in existing institutions and processes (Gürtler, 2023) . This includes corporate actors in the fossil fuel system, which wield significant power and influence. Long standing and persistent efforts by major oil companies to lobby government efforts to preserve the status quo to safeguard their business interests, coupled with efforts to undermine climate action and present the fossil-fuel system as lacking alternatives is delaying the energy transition.

The use of their vast resources to influence policies and public perception along with the technologies they choose to invest in impacts the choices available as well as energy pathways (Sidortsov and Katz, 2023) . Efforts to advance just energy transitions hence need to consider how to transform the wider political economy in which actions are taking place.

Justice over time

Politics and policy priorities are often driven by short-termism, yet energy decisions today ripple through time impacting future generations, but also the world's 1.8 billion young people. Drawing attention to the temporal justice dimension is aimed at expanding the time horizon of impacts and justice ramifications. This includes failure to anticipate and plan for energy transition impacts and put in place mechanisms that allow adversely impacted communities to prosper during the transition in under the new energy system. Intergenerational justice is a key element of the temporal dimension of just energy transitions and a long-standing legal principle (Redgwell and Rajamani, 2020).

Speed of the energy transition and impact on youth: In the energy space, intergenerational equity has been formulated to suggest that "future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today" (Sovacool et al., 2017). Intergenerational justice is also at the very heart of sustainable development; the UN in its preamble to the Agenda 2030 specifically states the determination "to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations" (Nations, 2015). The required speed of the energy transition is debated.

The importance of focusing on the temporal dimension for those focused on a rapid transition is the need to pay attention to short-term consequences. For those not considering speed it lays out how an energy transition compatible with climate objectives can be achieved. Impacts of climate change are already felt in every corner of the globe (IPCC, 2023b). The fossil fuel-based energy system is a major contributor to increasingly catastrophic climate impacts, from rising sea levels, extreme weather events and ecosystem disruptions. These impacts will disproportionately affect future generations.

The coming years will be critical for a chance to limit global temperature increases to 1.5°C, and to preserve a liveable planet for current and future generations (IRENA, 2023i). Choices in infrastructure today also create lock-ins and technological path dependencies affecting future generations, and mechanisms meant to manage carbon emissions via market-based mechanisms, such as CCS and carbon markets. Many Indigenous, youth and women's groups have criticised "false climate solutions" of phaseouts (Friends of the Earth International, 2023; Rose, 2024; Women & Gender Constituency, n.d.), while the UN Special Rapporteur on the Rights of Indigenous Peoples in 2024 called for a moratorium for carbon markets until COP29 (Amnesty International, 2024).

While energy sources such as sunlight, wind and water replenish, this is not necessarily the case with the materials needed for energy generation and distribution which can technically be depleted over time. This includes materials needed for the design of renewable energy technologies – including rare earth materials – as well as power lines and substantiations. Land use/siting choices along with the impact other environmental impacts described above can also impact the options and choices of future generations.

While these challenges pale in comparison to the issues raised by fossil fuel use or the problems raised by nuclear waste, policy makers need to proactive address these issues as the energy transition unfolds. Importantly, as with many issues raised in this text, the challenges in front of us go far beyond simply the energy sector. The modern energy and resource intensive lifestyle prevalent in most industrialised societies has been identified as one of the greatest threats to future of humanity (Ohlsson and Skillington, 2023)

Procedurally this entails ensuring involvement of youth and full consideration of the needs of future generations in planning processes. Recognising the rights of children and future generations to an environment that enables their full health and subsistence is key. Yet, few mechanisms exist to account for future needs, although recent ground-breaking climate litigations centred around intergenerational justice claims are highlighting avenues in this regard.

Existing and emerging justice issues

Comprehensive understandings of energy justice require broadening the lens beyond the deployment state of energy, such as subsequent job losses in the fossil fuel industry.

The energy life cycle includes extraction, manufacturing, project construction, installation and grid connection, operations and maintenance, energy delivery and end-of-life management.

Mapping the full range of injustice across the energy supply chain can help with better communicating injustices to end-users and the wider public but also allocate responsibilities for action. Renewables like any other infrastructure is not free from environmental, economic, and social impacts, though these are less catastrophic than conventional sources. Nonetheless, they have justice implications that need to be considered as part of the energy transition across their life cycle:

- Resource extraction, which is needed also for the production process for transition-minerals and materials, is associated with wide-spread human rights violations including environmental degradation, pollution, dispossession and land-grabs as well as neo-colonialism (Bainton et al., 2021; UN Permanent Forum on Indigenous Peoples, 2022). Over 500 human rights allegations related to extraction of transition minerals have been traced over the past decade (Business & Human Rights Resource Centre, 2023).

- Manufacturing energy-transition related technologies entail a number of economic benefits such as employment creation, economic development as well as export opportunities, but these remain geographically concentrated in a few markets, and benefits from value additions inequitably distributed. (IRENA and ILO, 2023b). Human rights abuses, particularly forced labour and modern, are also concerns that are prevalent and need to be addressed and prevented in RET manufacturing. (Clean Energy Council, 2022)

- Renewable energy deployment can entail significant justice challenges, especially where renewables are deployed at utility-scale. Human rights problems can include land rights and displacement along with environmental and socio-cultural impacts related to changed land use, while communities who live on the land that is being used don't always benefit from improved electricity access. Large-scale hydropower can have particularly detrimental impacts on humans and the environment. (Agrawal et al., 2023b).

- Finally, proactive approaches are needed to design circular economy approaches to reduce waste at the end of life of RETs and restore areas impacted by mining. The energy transition has significant resource and environmental implications, underlining the importance of policies that rely on circular economy approaches. The economy, and by extension the energy system, are largely built on linear economic model in which resources are extracted, transformed, used and finally discarded. The two leading renewable energy technologies today, solar PV and wind power, are projected to provide the majority (18,200 GW for solar PV, 10,300 GW for wind installations) of total installed renewable energy capacity (33,216 GW) in 2050 worldwide, in line with a climate-safe pathway within the 1.5 °C scenario (IRENA, 2023i).

Cumulative solar PV waste could reach more than 545 million tonnes globally by 2050 (IRENA, forthcoming), while waste from wind turbine blades could reach a cumulative 43.4 million tonnes by 2050 (Liu and Barlow, 2017). Designing a circular economy for renewable energy technologies is vital to address challenges of increased material demand and waste.

Across all stages, the decent work agenda also needs to be considered to improve workers welfare along with attention to distributional and recognitional justice issues from equal opportunities for disadvantages groups as well as impacts on community well-being. The fact that many of these impacts are invisible to energy consumers by distancing and displacing of burdens across the chains, including internationally, adds to the problem of addressing these challenges. (Bouzarovski et al., 2017). The adverse impacts of the fossil fuel energy system across the live cycle are thus noted and need to be further documented.

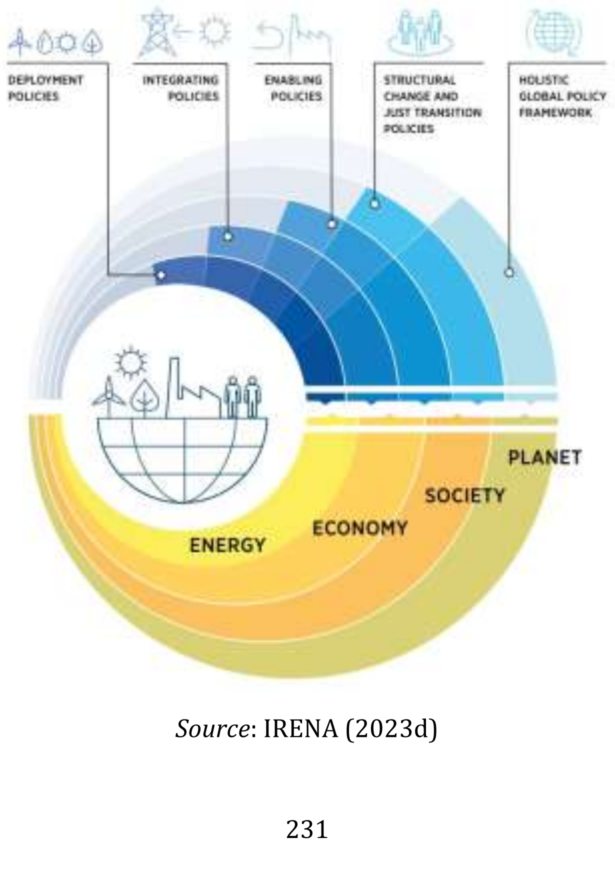
7.4 Application of Justice and Social Acceptance Dimensions

The notions of a just energy transition considered above can be used by policymakers to broaden their understanding of public acceptability dimensions of energy transition policies. They can be applied to individual measures and broader energy strategies and plans, while helping the identification and articulation of energy injustices that need to be addressed.

As the author has witnessed throughout the research period, and literature covered so far underscores, accelerating the energy transition in line with global climate and development ambitions requires a wide range of policies. To increase the share of renewables, this includes deployment policies that support scaling up of renewable energy capacities, policies that help integrate renewables into power grids, and integrate them in other energy delivery systems.

IRENA research made clear the importance of structural and just transition policies, industrial policies, education and training strategies, labour market measures and community investments, with adequate financing for countries to benefit from the transition. (IRENA, 2021, 2023d) – see *Figure 46* (below):

Figure 46: WETO Integrated Policy Framework



Source: IRENA (2023d)

Due to the far-reaching consequences of energy transitions, policies need to be considered and implemented in the context of more holistic considerations of interactions between the energy, economy, society and the planet. As has been highlighted throughout this text, countries energy choices have global impact including on the demand for minerals (e.g. to produce renewable energy technologies or batteries), land (e.g. for biofuels) or waste processing. Similarly, choices made today impact future generations.

7.4.1 Ownership, Benefits and Access

Already today, the social and economic benefits and costs in existing energy systems are not borne equally (IRENA, 2023d). Designing just policies requires taking into account the full range of distributional consequences of energy transition processes, climate imperatives and development needs, alongside existing and expected inequalities. Interventions need to consider both injustices of the current energy system, as well as those that might arise during the transition.

Ownership: Ownership and profits of the resources underpinning the current fossil-fuel dominated energy system is highly concentrated in the hands of a few large companies, energy exporting companies and financial institutions (Biswas et al., 2022). Who controls and owns energy projects and infrastructure, as well as how revenues and benefits are distributed has justice implications. When social dialogue takes place, companies that engage communities in addressing to gain insights into their needs, priorities and concerns experience a smoother energy transition pathway (IRENA Coalition for Action, 2023). As IRENA Coalition for Action member, ACCIONA, illustrated in the below case study, involving local communities enhanced social acceptance with benefit-sharing:

Corporate social responsibility in the EU – ACCIONA Energía and local communities

ACCIONA Energía is a global energy company operating exclusively in renewable technologies for more than 30 years. It prioritises social initiatives that create local value and are identified through social dialogue and participation. As part of its Social Impact Management model, the company organises community round-table discussions to listen to the needs and priorities of the communities where it operates and, on this basis, a customised social action plan is drawn up. The purpose of these discussions is to provide information on the project being developed by Acciona, to open communication channels and, above all, to reach a consensus on the social investment initiatives to implement. The events are usually attended by local social and cultural associations, social centres and some landowners and nearby residents. For instance, in 2022 at its photovoltaic plant in Bolarque (Cuenca, Spain), residents decided to carry out a project to revitalise the local olive oil co-operative, which was in difficulty. A social enterprise with expertise in rural areas, Agrovidar, was hired by ACCIONA Energía to provide a diagnosis, develop a strategy and business plan, and implement improvement measures. As part of the study, Agrovidar surveyed all members of the co-operative and people from the municipality to assess perceptions of the co-operative. The resultant measures, collectively agreed with the farmers, include theoretical and practical training sessions aimed at improving olive oil production and a communication plan to improve branding. An impact measurement study is being carried out and a significant impact on profitability and the employment generated by the co-operative has already been observed.

Source: IRENA Coalition for Action, 2023

As demonstrated, social dialogue can be a key enabler of broad community consensus and acceptance. It showed that a wide range of stakeholders, including employers and employees need to have a seat at the table to ensure benefits are shared equitably. Stakeholder engagement can involve government, private sector and civil society organizations, with different types of formal and informal negotiation, consultation or information sharing, as illustrated in the following case study by other company the author collaborated with while at ACCIONA:

Union jobs for the US workforce – Ørsted and NABTU Partnership

Ørsted - an international renewable energy company leading in offshore wind power - and North America's Building Trades Unions (NABTU) established a partnership with the ambition of creating a framework designed to facilitate the transition of US union construction workers into the offshore wind industry. As a result of the partnership, Ørsted and NABTU announced a Project Labor Agreement - the National Offshore Wind Agreement (NOWA) - to construct Ørsted's offshore wind farms with an American union workforce. A first-of-its-kind in the United States, the NOWA sets the industry standard from the outset and raises the bar for working conditions and equity, injects hundreds of millions of dollars of middle-class wages into the American economy, creates apprenticeship and career opportunities for communities most impacted by environmental injustice, and ensures projects will be built with the safest and best-trained workers in America. The NOWA covers all of Ørsted's contractors and subcontractors that will perform offshore wind farm construction from Maine to Florida.

Source: IRENA Coalition for Action, 2023

It showed the need for a conducive environment facilitating labor inclusion, partnerships between governments, industries and unions; and local, regional and international dialogue processes. However, benefits should also be accessible to all irrespective of gender, education or background. There are benefits in a diverse workforce, in a male-dominated sector, as shown in the next case study:

Gender access to skills in Brazil – Neoenergia School of Electricians for Women

Iberdrola, a global power utility through its Brazilian subsidiary Neoenergia established a School of Electricians uniquely for women in 2019, with the aim of encouraging female entry into this field and given their low enrolment in the original mixed school. Initially, the company anticipated that the major challenge would be recruiting women who were interested in training for a career as electricians, historically a male-dominated sector. A partnership with the state government helps women obtain a driving licence, thereby removing a potential barrier. In addition, information sessions were organized for women already working for the company to share their experiences. Training programme courses were set up in conjunction with Foundation for Technology Support São Paulo and the National Service of Industrial Training. The courses are available in São Paulo, Bahia, Pernambuco, Rio Grande do Norte and Distrito Federal. This approach helped to provide the instruction and curriculum needed to ensure that women felt engaged and included. The company also started a mentoring programme with volunteer employees to maintain student engagement with the company. The courses prepare women to gain employment within energy distribution companies. They include basic training for electrical power distribution network electricians. Upon completion of the course, students are able to work on the electrical power system in de-energised structures of up to 13.9 kV. In 2022, given the importance of the School of Electricians for women's inclusion in the workforce, the Board approved two environmental, social and governance objectives to be achieved by 2030 - for women to account for 35% or graduates from the course and 12% of professional electricians at Neoenergia.

Source: IRENA Coalition for Action, 2023

7.4.2 Interests, Values and Rights

Social interests, values and human rights come at play in order empower those suffering from inequalities. It requires acknowledgment of the different vulnerabilities and inequities communities are exposed to.

That is one important condition to then enable communities to participate in the very processes that will influence how the benefits of the energy transition are shared, as shown in the following case study from EMDEs and SIDS in Africa:

Local development across Africa – Community trusts in Kenya and Cabo Verde

Community trusts are set up as non-profit organizations, often governed by boards of trustees and elected members giving communities a say in benefit-sharing, some include 50% women as trustees, others engage them in capacity development activities to foster stronger governance.

In the Kipeto wind project in Kenya the board of trustees control income received from the ownership of 5% of the diluted equity in Kipeto Energy limited, which pledged 20 million Kenyan shillings during construction. It supports the community surrounding the Wind Farm Development at Kipeto. Its set up process included negotiating defined beneficiaries based on inclusive and culturally respectful consultations; defining the area of influence where benefits would be distributed based on robust stakeholder engagement; and, drawing legal agreements, dispute resolution mechanisms. The project also committed to vulture protection, not only strengthening social acceptance but also enhancing environmental stewardship.

In the Cabeolica Wind Farm in Cape Verde local communities around the farms are guided by a social and environmental plan. The project was incepted in 2009 and generated power in 2011 feeding electricity to the grids of four islands (Sao Vicente, Santiago, Sal and Boa Vista). Post-construction of the Santiago wind farm, small farmers who previously grazed their cattle on the land purchased by the wind farm were allowed to return under agreed safety conditions. Since 2013, the project has invested in an environmental education programme in schools and local communities that aim to promote local environmental awareness about the need to conserve local species (e.g., island birdlife) and the importance of renewable energy.

Source: IRENA, 2024b (*forthcoming*)

Community trusts are one way to ensure people or groups often marginalised. Energy transition interventions that enable the active participation of local stakeholders help building trust and achieving high levels of public acceptance (IRENA Coalition for Action, 2024).

7.4.3 Social License to Operate

License to operate requires energy transition strategies and processes in place to ensure justice is institutionalized. Where a renewable energy project is sited or located, how is land owned and accessed requires consultation and negotiation (IRENA, 2024b, forthcoming). This is particular important in places with communal stakeholders or leased land from commercial farmers, like in the South African case (below). When land ownership arrangements are heavily influenced by colonial history and segregation. The socio-cultural and political dimensions can be very complex, but inclusive land acquisition strategies offer better prospects for local communities, like direct financial participation, land share rights (IRENA 2024b, forthcoming):

Meaningful participation on wind projects – Communal land in South Africa

Land acquisition strategies determine where a project is sited. Commonly, projects in the region are either located on land owned and prepared for the project by national government, land accessed via negotiations with communal stakeholders or leased land from commercial farmers. The latter is especially the case in South Africa, where land ownership arrangements are heavily influenced by the colonial and Apartheid history of the country. On the other hand, in most of SSA, most land is owned by respective states but is managed under communal governance, a system under which land is collectively held and managed based on traditional customs and rules (Slavchevska et al., 2020). For instance, The Wesley-Ciskei Wind Farm leases land from a 28-member farmer co-operative established to serve as a contractual partner in the wind project. As part of the process, the developer financially and legally supported the farmers on communal land to acquire land title deeds. This was made possible through the corporate culture of a project development team that prioritised the potential socio-economic outcomes for the landowners and made required resources available (e.g., access to a relevant network of professionals to support the process).

Source: IRENA, 2024b (*forthcoming*)

7.4.4 Legal Compensation

When injustices occur in the fossil-fuel or the renewable-based energy sector, the remedy or lack thereof becomes paramount. Free, prior and informed consent is critical, and so is proper compensation mechanisms, as it would be in the case of displacement or resettlement (IRENA, 2024b forthcoming). The restorative measures might also need to address both past and current negative impacts of the energy transition.

Yet, literature on green jobs is also highlighting the opportunities not only repair harm, but also do good, with social and environmental interventions becoming economic opportunities to realize the just energy transition promise (Alfaro-Pelico, et al., 2023). There are examples that show both human and nature restoration interventions can go hand in hand, with the same principle of ensuring people can be part of the solution, rather than just the problem.

In Australia, for instance, community energy allows collective decision-making in the vicinity of a project by farmers, fisheries, food producers, or cultural and educational institutions (see box, *below*). Not only lead to solutions to local issues, but also the distribution of revenues (IRENA Coalition for Action, 2024).

Community grants programme in Australia

The first community owned wind power cooperative in Australia distributes part of its profit through the Community Grants programme which funded 60 local projects with grants totalling over $115,230 since 2011. Responding to the voices of the community, Hepburn Energy renewed the program as Impact Fund and set the goals, to contribute to the shire's zero-net emissions target by 2030 and to enable a thriving, resilient community and ecosystem that can regenerate in the face of climate change impacts. In 2022, Impact Fund contributed to the Community Power Hub programme which supports other communities to start energy projects. This programme is an initiative by the Victoria State Government aimed at supporting community-driven renewable energy projects by providing funding, expertise, and resources to help communities develop and implement their own renewable energy solutions. Impact Fund also contributed to the Trentham Carbon Forestry Project which works with local landholders to increase sustainable woodlot management by building carbon sinks and enhancing biodiversity, and Wattwatchers to install demand management packages to help local schools monitor and save on energy).

Source: IRENA Coalition for Action, 2024 (*forthcoming*)

This PhD thesis has shown that energy transitions in developing and emerging economies increasingly require not only technological and financial innovation but also legal and institutional mechanisms that ensure fairness, compensate affected communities, and create shared economic value. Building on the earlier analysis of derisking, other comparative case studies from the Caribbean, Sub-Saharan Africa, and IRENA-documented transitions in other regions show how restorative and compensatory measures align climate and development goals.

Sub-Saharan African Countries

Legal and institutional restorative measures have evolved primarily around hydropower and grid-expansion projects, but similar principles now inform renewable energy initiatives.

For instance, the Bumbuna Hydroelectric Project (Sierra Leone), included a Resettlement and Livelihood Restoration Plan anchored in statutory compensation and local livelihood grants. This precedent now informs solar-hybrid mini-grid projects under the Rural Renewable Energy Project. Despite implementation challenges. It also demonstrates the gradual mainstreaming of rights-based compensation within energy access programs.

In Kenya, the Energy Act (2019) institutionalized the Community Development Agreement framework. It required developers of large-scale energy projects (geothermal, wind, or solar) to allocate at least one percent of annual revenue to local development trusts. The mechanism proved instrumental in the Lake Turkana Wind Power Project, where legal compensation and benefit-sharing arrangements reduced social conflict and enhanced local acceptance. As IRENA (2020) noted, such legally-codified restorative obligations transform potential social liabilities into co-benefits that sustain long-term project stability.

In Namibia and Botswana, pilot community solar farms have employed compensation through lease-to-own land agreements, granting participating communities equity stakes over time. These initiatives highlight how restorative measures can evolve from one-off compensation to structured co-ownership models, aligning with the “just transition” principles outlined in IRENA’s Renewable Energy Transition Outlook: Sub-Saharan Africa (2023).

<u>The Caribbean Region</u>

Small island states begun integrating legal compensation clauses into renewable energy procurement contracts. Jamaica’s Electricity Act (2015) and the accompanying Integrated Resource Plan (2020) stipulated community consultation and benefit-sharing as conditions for licensing independent power producers. For instance, in the Paradise Park Solar Farm a local employment quota and a community development fund were included in the power purchase agreement to offset social and environmental disruption during construction. These measures, though limited in scale, demonstrate the potential for legally mandated social restoration linked to private-sector participation.

In Barbados, compensation mechanisms were embedded in the island’s Fair Energy Transition Policy. They mandate that households displaced by grid modernization or solar farm development receive either direct compensation or subsidized participation in the national rooftop-solar scheme. The IRENA–CARILEC (2022) review identified this approach as a socially integrative model, converting transitional disruption into community co-ownership opportunities.

Other Regions

Australia's community energy framework offers a mature model of how legal and economic restoration can foster both repair and growth. State-level schemes in Victoria and New South Wales legally mandate community benefit-sharing agreements and co-investment options for residents near renewable energy zones. According to the Australian Energy Market Commission (2021), these mechanisms have generated local reinvestment multipliers exceeding 2.5. They demonstrate that compensatory obligations can serve as growth catalysts rather than compliance costs. Like in the Caribbean and Sub-Saharan African economies, such models underscore the potential for locally anchored renewable industries that distribute value creation across society.

7.5 Consideration of Just Energy Transition Dimensions

While the effects of climate change are increasingly evident, the world is not on track to achieve global climate goals and deliver on energy transitions that ensure affordable, reliable, sustainable, and modern energy for all in line with Sustainable Development Goal 7. Radical action is needed not only to tackle the climate crisis but also to address widespread injustices within the energy systems. Over a quarter of the global population lacks clean cooking access and 8% still live without electricity (IEA et al., 2024).

Numerous households in both developed and developing economies are struggling with their energy bills. The social dimensions of the energy transition can play an important role in accelerating renewables' deployment while filling justice and inclusion gaps. Across energy justice lenses, giving more decision-making power to individuals and communities remain for increasing public support. The chapter has also underscored that ultimately justice – both as a demand and as a recognizable outcome – acquires meaning only within the specific context of the energy transition. It cannot easily be defined in the abstract, a priori or top down. Suitable approaches and policies have to be developed by relevant stakeholders and be sensitive to their geographical, political, cultural and social contexts.

For instance, the lived experiences and priorities of energy workers and communities in developing countries are different from people in advanced economies. More than a precise definition, what matters is whether appeals to justice in the energy transition context shape public and private policies to achieve desired outcomes. A just and inclusive energy transition might be conceived both as a process and a vision. Policies and measures need to be discussed and negotiated, designed, and ultimately implemented in a social context. As shown in the chapter, there is a variety of justice dimensions arising throughout the energy transition; some mutually reinforcing, some requiring difficult trade-offs.

Consistent with the above considerations, there is no one-size-fits all solution, and no single policy instrument that can ensure that energy transitions are just and inclusive. Yet, fundamental principles and standards are needed to ensure outcomes that are broadly accepted and supported. Given the far-reaching nature of the energy transition, it will likely entail a complex patchwork of different policies across different sectors, regions and nations.

Ensuring policy coherence requires common objectives formulated as part of a larger vision. Consensus on the outcomes of what is considered a just and inclusive energy transition pathway is key to facilitate collective action (IRENA, 2025 forthcoming). This section attempted to underline that while different conceptions of justice and inclusive can pose obstacles to forming consensus, it will be important to focus on areas of convergences for progress on what can be achieved collectively.

Across these cases, a common lesson emerged that legal compensation frameworks are most effective when paired with economic opportunity creation. In Jamaica, local maintenance contracts for solar and wind projects prioritize youth and women trainees certified under renewable energy programs. They convert the engagement around compensation into capacity-building dividends. In Sierra Leone and Kenya, revenue-sharing schemes supported environmental restoration, such as reforestation of hydropower catchments and community water systems, linking energy transition to ecosystem repair.

These experiences confirm the argument that just transitions are not solely distributive but transformative. By embedding legal restitution in the design of renewable projects, governments can mitigate short-term social costs while catalysing inclusive green-growth pathways in line with Sustainable Development Goals 7 (sustainable energy for all), 8 (decent jobs for all) and 13 (climate action). The comparative evidence has three overarching implications:

1. *Codification of Benefit-Sharing* - Making compensation mechanisms legally binding, through energy acts, licensing terms, or standardized PPAs, ensures predictability and equity in benefit distribution.
2. *Integration with Financial Derisking* - Restorative measures complement financial derisking instruments by reducing social-conflict risk, thereby lowering perceived investment risk. This synergy could be more explicitly reflected in the next iteration of the DREI framework.
3. *Local Co-ownership and Green Employment* - Transforming compensation into participatory equity and skills programs embeds communities in value chains, ensuring the transition delivers both repair and growth.

In conclusion, the comparative review from the Caribbean, Sub-Saharan Africa, and Australia demonstrates that legal compensation and restorative measures are not peripheral safeguards but core instruments of a just and inclusive energy transition.

Their inclusion not only enriches the analytical scope of the thesis, but also reaffirms its central proposition that systemic derisking must integrate social, legal, and environmental dimensions for sustainable development outcomes.

8 Conclusion

8.1 Summary

The thesis has assessed the barriers to the deployment of renewable energy. The frameworks chosen to evaluate these barriers (Lancaster University's North-West Hydro Resource Model, United Nations Development Programme Derisking Renewable Energy Investment model) were used to analysis actual investments, with initial focus on hydropower investment dynamics, while also covering solar and wind power. This research examined the multidimensional barriers to RE investment across diverse geographies, applying and adapting both reference sequential decision-making models and derisking frameworks.

The thesis established a comparative foundation to understand how policy, financial, technical, and social dimensions influence renewable energy transitions at different scales and under varying geographic, climatic, and institutional conditions. The application of these models to alternative renewable energy sources (e.g. wind, solar, ocean, biomass, geothermal), different areas of the world (e.g. Africa, Latin America, the Caribbean) and various scales (e.g. small, large) has furthered my own understanding of the barriers to the deployment of renewable energy. The research aimed to answer three core questions:

1. Can approaches to assess barriers to renewable energy deployment be developed into globally relevant generic models for any renewable energy source?

2. How would model parameters need to be modified for applicability in different areas of the world?

3. Is the model constrained by the scale of deployment?

Through the nine case studies — spanning Equatorial Guinea, South Africa, Namibia, Panama, Paraguay, Mongolia, Tajikistan, Barbados, and Jamaica — the research identified cross-regional patterns, assessed the influence of geography and scale, and proposed model modifications to integrate climate resilience, human capital development, and just transition dimensions. In answering these questions, this thesis has demonstrated that the NWHRM and DREI frameworks can, in principle, be adapted and applied globally across various contexts and renewable energy types. However, key constraints related to environmental, financial, technical and social factors influencing renewable energy deployment require modifications for their successful global application.

8.2 Research Findings

8.2.1 Development of Globally Relevant Models

The thesis found that while the NWHRM was designed to address the barriers to small-scale hydropower in the UK, its principles can be extended to other renewable energy sources, including solar and wind. Similarly, the DREI model, designed for renewable energy deployment in emerging markets and developing economies (EMDEs), is adaptable for broader use in both developed and developing countries. However, the thesis highlights that while these models offer a solid theoretical framework, practical adaptation is essential. For example, geographic factors (resource availability, infrastructure), social acceptability, and economic feasibility need to be integrated into the models when applied to new regions or renewable energy sources.

The adaptation of the NWHRM and DREI frameworks confirmed their relevance as decision-support tools in emerging markets and developing economies, when adjusted for contextual, spatial, and socio-political variables. The DREI framework proved effective in quantifying investment risk, while the NWHRM allowed for an assessment of resource feasibility, capacity, and public acceptability, particularly in hydro-dependent and data-scarce contexts. Of note, the NWHRM was originally developed in the UK to evaluate the site-specific feasibility of small-scale hydropower projects, using a combination of technical, economic, and environmental indicators.

The core principles of the model that make it extensible to other renewable energy sources are: (a) *Resource Potential Assessment* - quantifying renewable resource availability (e.g., water flow in hydro, solar irradiation, or wind speed) and matching it with technology performance parameters; (b) *Infrastructure and Accessibility Analysis* - evaluating the proximity of potential generation sites to existing grid, transport, or market infrastructure, which determines cost efficiency and technical viability; (c) *Economic Feasibility Assessment* - integrating capital, operational, and maintenance costs into a simplified Levelized Cost of Energy framework, to compare different technology options; (d) *Public Acceptability and Environmental Sensitivity* - considering local stakeholder attitudes, land-use conflicts, and environmental constraints as critical factors influencing project approval and sustainability; (e) *Decision-to-Build Logic* - combining resource, economic, and social indicators into a structured decision pathway that identifies whether a project is viable, marginal, or non-viable.

That said, the original NWHRM embedded geographic, social, and economic dimensions with a narrower focus than the thesis proposes. For instance, geographic factors were limited to hydrological resource potential, site slope, and flow data within the UK's dense infrastructure context. Economic feasibility was modelled under uniform regulatory and financial assumptions, reflecting stable market conditions and subsidies in the UK. Social acceptability was treated primarily through environmental sensitivity screening (e.g., river habitat conservation), not as a participatory or socio-economic dimension.

The thesis advanced both models by: (1) Integrating social acceptability and justice parameters, building on experiences from Jamaica, Barbados, and South Africa; (2) Incorporating climate resilience and adaptive management, derived from hydro and hybrid systems in Tajikistan and Paraguay; and, (3) Embedding human capital and gender dimensions, based on workforce development and local content measures observed in Namibia and Jamaica. These refinements would render both models more inclusive, from technical optimization to systemic derisking encompassing social, environmental, and institutional risks.

8.2.2 Modifications to Model Parameters

Both models require modifications for global applicability, particularly in terms of financial and regulatory environments. The DREI model's assumptions about financial derisking mechanisms (e.g., non-grant instruments) must be adjusted to the local regulatory, market, and economic conditions of different countries. For developed economies, market-based incentives and regulatory structures are more mature, requiring less financial support compared to the EMDEs, which rely heavily on international funding and policy interventions to mitigate risks.

The areas of specific adaptation of the DREI model include the: (1) Addition of public acceptability multipliers capturing social and gender inclusion (Jamaica, Namibia); (2) Development of resilience-adjusted cost of capital parameters, linking climate exposure to financing cost reductions (Mongolia, Paraguay); (3) Expansion of policy derisking instruments to include compensation mechanisms and legal frameworks enhancing investor confidence (South Africa, Panama).

Similarly, the NWHRM needs adjustments when applied to larger renewable projects (e.g., wind farms) or to different geographies (e.g., SIDS, dry regions) that present distinct ecological and technical challenges. The derisking applications across Sub-Saharan Africa, Latin America and Central Asia showed that climate risks pose a barrier to deployment of hydropower. They also impact operation and maintenance of existing capacity due to failure to consider short-to-medium climate risks that directly impact technical and financial performance, safety, health and environmental concerns, and overall power system reliability.

As a result, the NWHRM would benefit from the: (1) Inclusion of seasonal climate vulnerability indices, particularly relevant for hydro systems in Tajikistan and Equatorial Guinea; (2) Integration of community participation and benefit-sharing coefficients, informed by local ownership schemes in Barbados; (3) Adjustment of decision-to-build thresholds to reflect financial derisking measures applicable to public–private partnerships. The thesis expanded and recontextualized the NWHRM principles to make the model globally relevant and applicable to other renewable technologies, as listed in Table 33 (*below*).

Table 33: NWHRM Modifications

Original NWHRM	Proposed NWHRM Modifications	Considered Case Studies
Hydrological resource mapping	Multi-resource mapping (e.g., solar irradiation, wind speeds)	Namibia (solar), Mongolia (wind)
Uniform market context	Variable economic feasibility reflecting financing risk and WACC	Paraguay, Panama
Infrastructure proximity	Grid connectivity and storage integration	Barbados (distributed solar)
Environmental sensitivity	Full social acceptability: community benefit, gender inclusion, social license	Jamaica, Equatorial Guinea
Technical design decision	Broader “decision-to-deploy” incorporating climate resilience and policy stability	Tajikistan (hydro resilience), South Africa (policy derisking)

The NWHRM model already contained these conceptual categories, but based on the thesis evidence they would need adaptation. For instance, geographic factors would include climate resilience, infrastructure maturity, and logistics constraints. Additionally, social acceptability would explicitly integrate justice, gender, and community ownership dimensions. Meanwhile, economic feasibility would specifically reflect risk-adjusted costs, as per DREI framework while also integrating their dynamic nature not captured by the static LCOE computations.

Some of these considerations are covered by existing environmental and social standards and safeguards, including those followed by multilateral development banks, such as the World Bank Group or the European Bank for Reconstruction and Development. However, their focus is on traditional aspects, such as dam safety, natural habitats protection and resource efficiency.

The case studies showed that the NWHRM is primarily site-focused and relatively static. The thesis proposes the incorporation of more dynamic, cross-sectoral, and context-sensitive aspects by: (a) incorporating geographic diversity (arid, tropical, mountainous); (b) embedding social and governance variables from the DREI framework; (c) integrating climate vulnerability and resilience planning into feasibility assessment.

These adaptations would allow decision-makers in emerging market and developing economy contexts to compare renewable technologies on a consistent multidimensional basis, not just technical performance. They would also be able to quantify how geography and scale affect both cost and social outcomes. These broader considerations would inform the identification of additional policy and institutional levers (e.g., tariff design, gender programs, infrastructure investment) that could reduce risk and enhance deployment feasibility. Further specific focus on climate change adaptation and ecosystem resilience is needed to broaden not only the ecological dimensions of the application of the North-West Hydro Resource Model, but also the consideration of risks under the Derisking Renewable Energy Investment model.

Together, these modifications would create integrated analytical approaches capable of identifying both financial and non-financial enablers to accelerate renewable energy investment. Therefore, the core principles of the NWHRM sequential decision-making could be adapted to other renewable energy sources. Expanding its geographic context and socio-economic dimensions would capture regional diversity, social inclusion, and investment risks further aligned with the DREI framework. These adaptations would allow the models to evaluate solar, wind, and hydro projects within an integrated, derisked decision support structure that reflects the social, physical, financial and political context.

8.2.3 Scale of Deployment

The research confirmed that scale plays a critical role in determining the barriers to deployment. The scale of renewable energy deployment emerged as a decisive factor in cost structures, technical performance, and institutional feasibility.

Smaller-scale projects, like microgrids or off-grid solar, faced different technical and financial constraints compared to large-scale renewable energy deployments, such as utility-scale wind farms. Particularly in developing economies, access to finance, grid connectivity, and local expertise are dominant barriers. In Barbados or Jamaica decentralized and community-based projects proved effective in reducing import dependency and enhancing local ownership.

In contrast, large-scale projects (e.g., Paraguay's hydropower and South Africa's wind power) benefitted from economies of scale but faced higher coordination, grid, and financing requirements. For larger systems, integration into national or regional grids and regulatory hurdles were more pressing.

Therefore, while the models can be adapted to different scales, each scale presents unique challenges that must be carefully considered when applying these frameworks. The Levelized Cost of Energy served as an indicative comparator across cases. LCOE integrates capital expenditure, operational expenditure, fuel and maintenance costs, and financing terms. Reductions in LCOE observed across the case studies ranged from 20% to 40%, depending on the derisking measures applied.

For instance, Mongolia's wind projects saw a 30% LCOE reduction through policy stability and concessional finance. Meanwhile, Namibia's solar CSP achieved ~25% reduction through technology learning and blended finance. Barbados' rooftop solar and Jamaica's Paradise Park project attained parity with fossil fuels due to improved FiT design and stable PPAs. South Africa's utility-scale wind projects achieved lower LCOE due to capacity factors above 35% and robust grid integration. In Barbados, limited grid capacity, import logistics and O&M challenges increased per-unit costs but benefitted from lower transmission losses and community resilience.

Optimal scale depends on geography, market maturity and institutional capacity, rather than technology alone. Indeed, geography strongly shaped technology selection and system design. In Equatorial Guinea and Tajikistan, abundant water resources but weak infrastructure justified a focus on small hydro with hybridization potential. Namibia's arid climate and high solar irradiation made concentrated solar power optimal despite high upfront costs, supported by concessional financing.

Mongolia's steppe regions offered superior wind potential, but low winter temperatures required technical adaptations and localized O&M capacity. Caribbean islands, exposed to hurricanes and high import costs, favoured distributed solar and microgrid systems for resilience. Paraguay's hydropower dependency demonstrated the need for diversification to mitigate climate risk and export concentration. The analysis thus linked resource endowment, spatial constraints, and climate exposure to the renewable energy technology of choice, which is a relationship central to refining both the NWHRM and DREI models.

Capital costs dominated renewable energy investment, with the cost composition varying by technology. For hydropower developments (Paraguay, Tajikistan, Equatorial Guinea), there was a high upfront CAPEX but low OPEX. The major operational risks stemmed from climate variability and sedimentation. In wind power (South Africa, Mongolia, Panama), with moderate CAPEX and low OPEX, maintenance and grid integration costs were significant. For solar power (Namibia, Barbados, Jamaica), despite comparatively declining CAPEX and low OPEX, battery and inverter replacement costs remained critical barriers.

But the thesis rendered both CAPEX and OPEX as relevant. Operational challenges included maintenance and spare parts logistics, which in remote or island settings (Barbados, Equatorial Guinea) led to high import costs and delays. The technical longevity, including component degradation (e.g., PV module efficiency loss or turbine fatigue) reduced long-term yields, if not mitigated by training and preventive maintenance. In addition, human capacity gaps became a key factor. Insufficient local technicians in Namibia and Jamaica highlighted the link between O&M efficiency and workforce development.

The Table 34 (*below*) provides a comparative analysis revealing that while financial and policy derisking measures reduce LCOE across all technologies, social, geographic, and institutional barriers remained dominant determinants of feasibility:

Table 34: Renewable Energy Technology Comparisons

Technology	Common Barriers	Case Studies
Hydro	Seasonal flow variation, sedimentation, land-use conflicts, high resettlement costs	Equatorial Guinea, Tajikistan, Paraguay
Wind	Policy uncertainty, grid congestion, social acceptance (noise, aesthetics), financing volatility	South Africa, Panama, Mongolia
Solar	Intermittency, storage costs, limited land, insufficient technical capacity	Namibia, Barbados, Jamaica

To remove these barriers, policy derisking instruments proved critical to complement financial derisking instruments, which only transferred the associated risk or burden of these barriers. The policy coherence and governance emerged as decisive in shaping investment climates. For instance, South Africa's Renewable Energy Independent Power Producer Programme (REIPPPP) demonstrated how transparent procurement frameworks could lower financing risk and catalyse private investment.

Jamaica and Barbados exemplify how strong regulatory institutions enhance investor confidence even in small markets. Equatorial Guinea and Tajikistan highlighted governance challenges (e.g., institutional fragmentation, limited transparency, and weak project monitoring), increasing risk perception and slowing adoption. Thus, the case studies underscored the need to balance state control, private participation, and social equity, as defining factors for successful deployment.

8.2.4 Next Steps

This thesis contributes to the growing body of knowledge on renewable energy deployment by providing a comprehensive analysis of barriers and assessing the applicability of the NWHRM and DREI models across diverse contexts. The findings demonstrate that while these models are robust, they require modifications to address the specific challenges posed by different geographies, scales, and renewable energy technologies. The research also underscores the need for cross-disciplinary approaches and collaborative efforts to enable a just, inclusive, and sustainable global energy transition. Building on the findings of this research, several next steps are recommended for both academic and practical applications.

<u>Model Integration into Decision-Making Tools</u>

The findings should be used to update both the NWHRM and DREI models, incorporating real-world insights from various renewable energy projects worldwide. These updated models should be made available to policymakers and project developers as part of decision-making tools tailored to specific geographic and technological contexts.

<u>Pilot Projects in EMDEs</u>

Given the challenges identified in the application of these models to emerging markets and developing economies, the next logical step is to undertake pilot projects in select EMDEs to test and refine the modified models. Countries in Africa, Asia, and Latin America offer diverse environments for trial implementations.

<u>Collaboration with Policymakers and Industry</u>

Future steps should involve close collaboration between academia, policymakers, and industry to ensure that model adaptations align with real-world demands. Engaging stakeholders in workshops and seminars could foster a better understanding of how to practically address barriers to renewable energy deployment, including new policy and financial interventions.

Capacity Building

It is crucial to invest in capacity building for renewable energy professionals, particularly in EMDEs, to develop the technical, financial, and policy expertise needed to apply these models effectively. Training programs, professional courses, and international knowledge-sharing platforms could help bridge the skills gap that currently exists in many developing regions.

8.3 Future Research Scopes

While this thesis has provided relevant insights into the applicability of the NWHRM and DREI models, several areas warrant further research, including:

8.3.1 Expansion to Emerging Energy Technologies

Future research could explore the adaptability of these models to newer renewable energy technologies, such as offshore wind, and consider hybrid approaches, such as those that integrate green hydrogen and advanced battery storage. These emerging applications present unique technical and regulatory challenges that have not yet been thoroughly explored within existing frameworks. In addition, the research should use DREI-adjusted financial metrics to capture resilience and dispatchability benefits.

8.3.2 Deepening Just Transition Dimensions

The role of social acceptance and community engagement in renewable energy deployment requires further exploration. While this thesis touched on the importance of social barriers, future studies could investigate community participation models, social equity considerations, and how renewable energy projects can be better aligned with local needs and values. Indeed, the application of enhanced models to measure gender equity, local ownership, and intergenerational employment impacts could provide stronger evidence for socially inclusive transitions, particularly in small power systems such as those assessed in Jamaica, Barbados and Equatorial Guinea.

8.3.3 Policy and Financial Innovations

Future research should focus on how innovative financial instruments, such as green bonds, climate risk insurance, and blockchain-based energy trading, can be incorporated into the DREI model to accelerate renewable energy investments. Similarly, examining new policy developments such as carbon pricing and net-zero commitments can enhance the model's relevance. Further exploration of sovereign guarantees, and other blended finance mechanisms would refine DREI parameters and provide scalable pathways for replication across EMDEs.

8.3.4 Cross-Cutting Comparisons

A comparative study of renewable energy deployment across various regions (e.g., Sub-Saharan Africa, Southeast Asia, and Latin America) and how different financial, regulatory, and social landscapes affect the application of these models would provide further insights into global applicability. Such comparisons could also explore cross-sectoral barriers, such as those found at the intersection of energy, agriculture, and water management. Comparisons across hydro-dependent (Paraguay, Tajikistan, Equatorial Guinea), wind-based (South Africa, Panama, Mongolia), and solar-based (Namibia, Barbados, Jamaica) contexts can help quantify trade-offs between cost efficiency, resilience, and social inclusion.

8.3.5 Post-Deployment Impacts

Understanding the long-term socio-economic and environmental impacts of renewable energy projects, especially in EMDEs, would be a valuable extension of this research. Future studies could track the sustainability, resilience, and benefits of renewable energy deployments after implementation to assess whether the initial barriers were sufficiently addressed and if new barriers emerged post-deployment. For instance, capacity building efforts should involve regional training hubs, model-guided decision tools enabling ministries to integrate derisking parameters into national RE planning, and partnerships with DFIs and universities to operationalize DREI and NWHRM applications through national energy modelling platforms.

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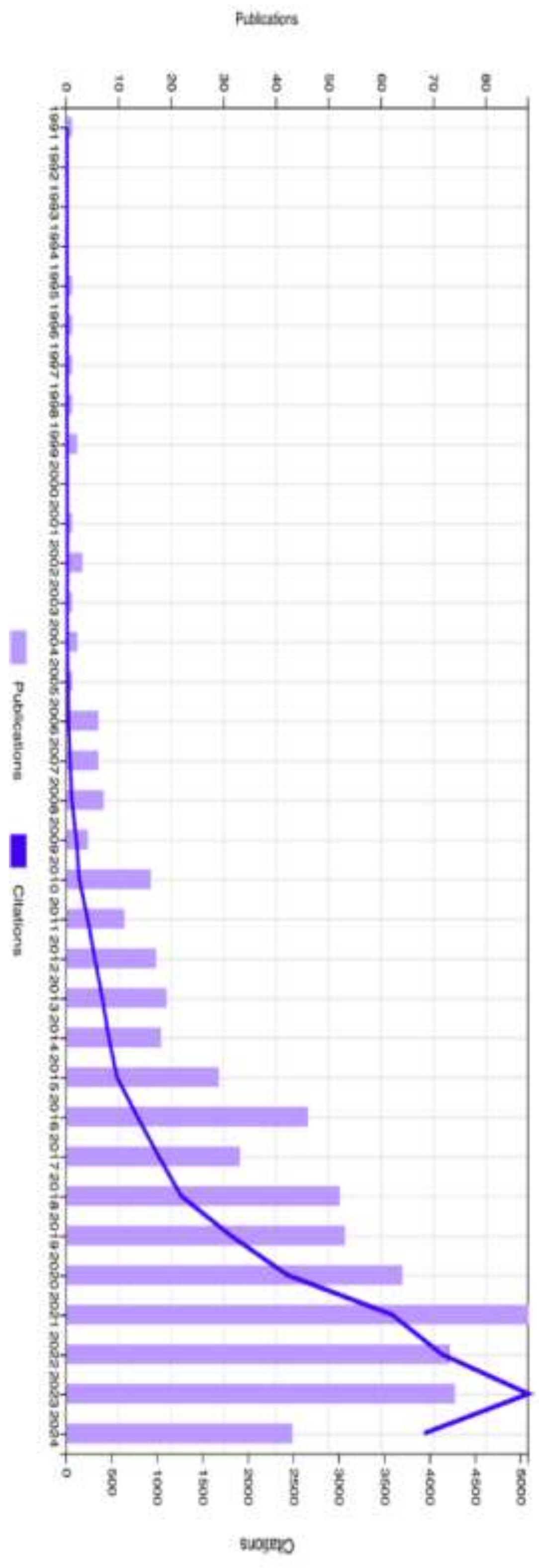
10 Appendices

Appendix A. Literature Review

Authors	Article Title	Year	Vol.	Is.	UT (Unique WOS ID)
Seetharaman; Moorthy, K; Patwa, N; Saravanan; Gupta, Y	Breaking barriers in deployment of renewable energy	2019	5	1	WOS:000460080900058
Nanaki, EA; Xydis, GA	DEPLOYMENT OF RENEWABLE ENERGY SYSTEMS: BARRIERS, CHALLENGES, AND OPPORTUNITIES	2018			WOS:000481900100008
Krupa, J	Identifying barriers to aboriginal renewable energy deployment in Canada	2012	42		WOS:000301616000070
Etezadi-Amoli, A; Choma, K; Ahmad, J	An investigation of select barriers and solutions for renewable energy deployment	2006			WOS:000247080003104
Foster, E; Contestabile, M; Blazquez, J; Manzano, B; Workman, M; Shah, N	The unstudied barriers to widespread renewable energy deployment: Fossil fuel price responses	2017	103		WOS:000397356000021
Sambodo, MT; Yuliana, CI; Hidayat, S; Novandra, R; Handoyo, FW; Farandy, AR; Yuniarti, PI	Breaking barriers to low-carbon development in Indonesia: deployment of renewable energy	2022	8	4	WOS:000799950700008
Laldjebaev, M; Isaev, R; Saukhimov, A	Renewable energy in Central Asia: An overview of potentials, deployment, outlook, and barriers	2021	7		WOS:000701691100014
Nasirov, S; Silva, C; Agostini, CA	Investors' Perspectives on Barriers to the Deployment of Renewable Energy Sources in Chile	2015	8	5	WOS:000356879600026
Apolonia, M; Fofack-Garcia, R; Noble, DR; Hodges, J; da Fonseca, FXC	Legal and Political Barriers and Enablers to the Deployment of Marine Renewable Energy	2021	14	16	WOS:000690547500001
Kachapulula-Mudenda, P; Makashini, L; Malama, A; Abanda, H	Review of Renewable Energy Technologies in Zambian Households: Capacities and Barriers Affecting Successful Deployment	2018	8	6	WOS:000436128300005
Kim, C	A review of the deployment programs, impact, and barriers of renewable energy policies in Korea	2021	144		WOS:000649677000003
Bukari, D; Kemausuor, F; Quansah, DA; Adaramola, MS	Towards accelerating the deployment of decentralised renewable energy mini-grids in Ghana: Review and analysis of barriers	2021	135		WOS:000593754500003
Ramesh, J; Ram, MM; Varadarajan, YS	Barrier mitigation strategies to the deployment of renewable and energy-efficient technologies (REET) in micro and small manufacturing clusters	2022	52		WOS:000820453600016

Source: Web of Science
(May 2024 "Title" Filter: Barriers AND Deployment AND Renewable AND Energy)

Appendix B. Thematic Search



Source: Web of Science

(September 2024 "All Fields" Filter: Barriers AND Deployment AND Renewable AND Energy)

Appendix C. Author Resume

RESUME

Dr. Raúl Alfaro-Pelico

Lancaster University, Bailrigg, Lancashire LA1 4YW (U.K.) • r.alfaro-pelico@lancaster.ac.uk

+12027907771 (USA) • +34652495850 (Spain) • +240222201094 (Equatorial Guinea) • dralfaropelico@gmail.com

- Experienced infrastructure sustainability, climate finance advisory and just & inclusive energy transition expert, promoting low-carbon, blue & green growth and climate-resilient development through public-private-philanthropic partnerships at international entities (*Green Climate Fund, Global Environment Facility, Climate Investment Funds, World Bank, Sustainable Energy for All, International Finance Corporation, Acciona, IRENA, IADB, UNDP-AfDB-RMI*).
- Demonstrated trajectory as an adviser, manager and researcher of high-risk impact climate investments and sustainable finance transactions towards derisking clean energy, industry decarbonization and resilient infrastructure deployments.

EMPLOYMENT

Since 2025	**LEAD SUSTAINABILITY CONSULTANT** – *Infrastructure & Energy*, The World Bank / *Investment Services & Readiness*, Green Climate Fund / *Industry Decarbonization*, Climate Investment Funds, Remote (Washington) *Developing public-private partnerships and derisking investment pipelines via project preparation facilities.*
Since 2024	**SENIOR RESEARCH FELLOW** – *School of Engineering*, Lancaster University Renewable Energy Group (U.K.) *Undertaking energy, economics and environmental modelling, finance and policy research through multi-level decision-support platforms.*
Since 2021	**SENIOR ADVISER** –*Private Sector Observer-WBCSD/IRENA Coalition for Action*, Climate Investment Funds / *Universal Energy Facility*, Sustainable Energy for All / *Sustainability Finance*, International Finance Corporation / *Global Environment Facility*, Inter-American Development Bank, Washington, DC. *Catalysing sustainable and infrastructure finance, climate and impact investments and ESG policy developments.*
2024-2025	**DIRECTOR** – *Knowledge, Policy and Finance Centre*, International Renewable Energy Agency, Abu Dhabi (UAE) *Overseeing IRENA's ESG risks, energy statistics and climate / resource assessments, and convening public-private just transition multi-stakeholders.*
2022-2023	**DIRECTOR** – *Energy Transition Academy*, Global South Program, Rocky Mountain Institute, Washington, DC. *Overseeing RMI's socio, techno-economic research, capacity building & investment derisking efforts through finance toward just energy transitions.*
2020-2021	**MANAGER** - *Sustainability Leadership*, ACCIONA (Energía & Infraestructura) S.A., Madrid (Spain), *Managing corporate strategy and competitive position in sustainable, blended finance in high-level platforms (UNFCCC, WBCSD, IRENA, UNGC, WEF, EU).*
2015-2019	**MANAGER** – *Environment & Natural Resources / Pilot Program for Climate Resilience* The World Bank, Latin America and the Caribbean (LAC), Washington, DC (U.S.A.) *Managing a 40+ climate and environment specialists of a US$2 billion low-carbon, blue and green economy, clean and resilient infrastructure work program and blended funds.*
2009-2015	**TECHNICAL ADVISER** – *Climate Change-GEF Unit*, United Nations Development Programme, Regional Hub (LAC)/Country Office (Namibia). *Advising on energy, technology & infrastructure, nature & climate finance in Africa & LAC regions.*
2007-2009	**DEPUTY FINANCE MANAGER** Noble Energy EG Ltd., Malabo (Equatorial Guinea) *Financial reporting, monitoring and liaising on E&S, finance and governance matters.*
2002-2007	**CAPITAL BUDGET COORDINATOR** – ExxonMobil, Malabo (Eq. Guinea)/Houston, TX (USA). *Stewarding corporate governance responsibilities, maintaining controls over infrastructure expenditure, energy efficiency & EHS risk compliance (ISO 50001/14001).*
2000-2001	**PROJECT & STRUCTURED FINANCE ANALYST** – Glencore, London (U.K.) *Supporting the credit analysis desk on the arrangement of commodity-backed financing.*

EDUCATION

2013-2023	**PhD in Engineering (Energy, Ecology, Economy)** *Lancaster University* (UK)
1999-2000	**M.Sc. in Economics (with reference to Africa)** *SOAS, University of London* (UK)
1994-1999	**BA(Hons) in Business Administration** *LMU* (UK)/Univ. Carlos III Madrid (Spain)