



Renewable Energy Methodology

*Assessing the greenhouse
gas impacts of renewable
energy policies*

ICAT series of
Assessment Guides



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Contributors & Acknowledgements

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How to use the ICAT series of policy assessment guides

This guide is part of the ICAT series of policy assessment guides developed by the Initiative for Climate Action Transparency (ICAT) to support countries in assessing the impacts of policies and actions. The ICAT series provides a coherent set of methodologies that can be applied individually or in combination, depending on assessment objectives and national circumstances.

This guide is intended to be used in conjunction with other ICAT policy assessment guides, and may also be applied alongside complementary guidance and tools.

This updated version of the guide, originally released in April 2020, expands the methodological coverage to include two additional renewable energy policy types, and incorporates substantive updates across several sections to reflect recent methodological developments.

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Table of Contents

Introduction

Chapter 1: Introduction	2
-------------------------------	---

Part I: Plan the assessment

Chapter 2: Planning the renewable energy policy assessment	8
--	---

Chapter 3: Overview of renewable energy policy instruments	10
--	----

Part II: Describe the policy and impacts

Chapter 4: Defining the policy, causal chain and GHG assessment boundary	17
--	----

Part III: Assess the policy

Chapter 5: Estimating renewable energy addition of the policy ex-ante	28
---	----

Chapter 6: Estimating GHG impacts of the policy ex-ante	55
---	----

Chapter 7: Estimating GHG impacts of the policy ex-post	82
---	----

Appendix A: Information to describe policy	87
--	----

Appendix B: Criteria for policy selection and overview of key policy instruments	94
--	----

Appendix C: Resources and examples to estimate RE addition	100
--	-----

Appendix D: Paris agreement crediting mechanism	145
---	-----

Appendix E: End to end example	154
--------------------------------------	-----

Templates	171
-----------------	-----

Toolkit	172
---------------	-----

Case Studies	177
--------------------	-----

Abbreviations and acronyms	211
----------------------------------	-----

Glossary	214
----------------	-----

References	222
------------------	-----

List of figures

Figure 1.1. Structure of the guide	4
Figure 1.2. A step-by-step approach to using the ICAT Renewable Energy Methodology to assess RE policies and actions.....	6
Figure 4.1. Overview of steps in the chapter	17
Figure 4.2. Example causal chain for RE policies.....	23
Figure 5.1. Flow chart – logic for applying the four-step approach	29
Figure 5.2. Steps for estimating RE addition of the policy ex-ante	30
Figure 5.3. Three policy scenarios and their implications for estimating the technical potential for the assessment period.....	31
Figure 5.4. Case I – policy with capacity cap over entire period of assessment	32
Figure 5.5. Case II – policy without cap set for entire assessment period	33
Figure 5.6. Case III – policy with capacity cap over partial period of assessment.....	34
Figure 6.1. Overview of steps in the chapter	55
Figure 7.1. Overview of steps in this chapter	82
Figure 6.D1. Flow chart to calculate the emissions from electricity consumption and/or generation for energy sources under scenario A.....	147
Figure E.1. Policy causal chain	158
Figure CS.1. Share of the Eswatini population with access to electricity	179
Figure CS.2. Causal chain diagram in the context of Eswatini RE policy application and grid electricity generation.....	184
Figure CS.3. Energy generation by technology in the BAU scenario (left) and the RE1 scenario (right).....	188
Figure CS.4. Causal chain diagram in the context of India RE policy application.....	196
Figure CS.5. States by total sanctioned and installed capacity (MW)	198
Figure CS.6. States by sanctioned and installed solar pumps (nos.), as of 28 February 2026	200
Figure CS.7. States by sanctioned capacity and installed solarized pumps (nos.), as of 28 February 2026	202

List of tables

Table 2.1. Mapping of UNFCCC CTF Table 5 reporting elements to sections of this guide.	9
Table 4.1. Examples of stakeholder responses to policy implementation and intermediate effects	19
Table 4.2. Types of GHG impacts.	20
Table 4.3. Examples of GHG emission sources associated with RE projects and policies.	21
Table 4.4. Example of GHG impacts and emission sources considered in defining the GHG assessment boundary	24
Table 4.5. Example of mapping policies that target the same emissions sources.	26
Table 5.1. Auction policies – influence of policy design characteristics on the technical potential.	37
Table 5.2. Barrier categories	47
Table 5.3. Sample template for barrier analysis.	51
Table 5.4. Summarized results for auctions (example 1) to increase RE additions.	54
Table 6.1. Brief description of the emissions trajectory method and grid emission factor method	57
Table 6.2. The IEA six-phase VRE integration framework	59
Table 6.3. Data and parameters typically used in estimating GHG emissions	62
Table 6.4. Examples of models that can be used to assess RE policies.	63
Table 6.5. Transmission and distribution losses (percentage of output).	66
Table 6.6. Factors to consider when assuming a continuation of historical trends in the electricity mix.	67
Table 6.7. Typical direct CO ₂ emission factors of power plant technologies (2019–2023).	70
Table 6.8. Future efficiency outlook for coal, gas and oil power plants	71
Table 6.9. Resources available for estimating emission factors based on the combined margin approach.	79
Table 4.A1. Checklist of recommended information to describe the policy being assessed.	87
Table 4.A2. Checklist of additional information that may be relevant to describe the policy being assessed	90
Table 3.B1. Overview of key policy instruments implemented in the energy supply sector in both developed and developing countries (2021)	95
Table 5.C1. Variables and parameters for calculating the LCOE of RE technologies	100
Table 5.C2. RE policy examples	101

Table 5.C3. Examples of available country-specific studies for national RE potentials	114
Table 5.C4. Examples of publicly accessible databases on RE resource availability	115
Table 5.C5. Support tools to estimate RE potential per technology based on different parameters obtained from international databases.....	117
Table 5.C6. Feed-in tariff policies – influence of policy design characteristics on technical potential	119
Table 5.C7. Tax incentive policies – influence of policy design characteristics on technical potential	122
Table 5.C8. Auction policies – influence of policy design characteristics on technical potential	123
Table 5.C9. Net metering policies – influence of policy design characteristics on technical potential	124
Table 5.C10. Variable RE integration with grid-battery storage policies – influence of policy design characteristics on technical potential	125
Table 5.C11. Barrier assessment template – simultaneous rating method	126
Table 5.C12. Barrier assessment example – pairwise comparison method	127
Table 5.C13. Summary of RE addition under FiT policy (example 2)	127
Table 5.C14. Summary of RE addition under net metering policy (example 3)	128
Table 5.C15. Summary of RE addition under VRE integration with grid battery storage policy (example 4).....	128
Table 6.D1. Default values for w_{OM} and w_{BM}	146
Table 6.D2. Examples of activities where case 1 or case 2 applies	148
Table E.1. Checklist of recommended information to describe the policy being assessed	154
Table E.2. Stakeholder responses to feed-in tariff policy implementation and intermediate effects.....	157
Table E.3. GHG source category for feed-in tariff policy.....	157
Table E.4. GHG impacts and emission sources considered in defining the GHG assessment boundary for the feed-in tariff policy	159
Table E.5. Interaction of feed-in tariff policy targeting the same GHG emissions sources as other policies	160
Table E.6. Matrix for rating policy design characteristics	161
Table E.7. Growth rates historical trends	165
Table E.8. Electricity generation mix 2027	166
Table E.9. Electricity generation mix 2040	166

Table E.10. Electricity generation by technology (baseline)	166
Table E.11. Emission factors per technology	167
Table E.12. Emission factors adjusted considering technology improvements	167
Table E.13. Absolute emissions from electricity generation (baseline)	167
Table E.14. Final generation per technology in 2040	168
Table E.15. Absolute emissions from electricity generation (policy scenario).....	169
Table CS.1. The Eswatini NEP	179
Table CS.2. GHG mitigation effects of the policy.....	180
Table CS.3. Overview of methodological considerations and assumptions	181
Table CS.4. GHG impacts and source categories included/excluded in the GHG assessment boundary	184
Table CS.5. Existing and projected RE generation capacity by 2030	185
Table CS.6. Emissions and mitigation outcomes by 2030	185
Table CS.7. Overview of PM-KUSUM policy	190
Table CS.8. Overview of PM-KUSUM policy.....	192
Table CS.9. Overview of methodological considerations and assumptions	193
Table CS.10. GHG sources and their impact under the PM-KUSUM scheme in the assessment boundary	196
Table CS.11. Results for component A	197
Table CS.12. GHG mitigation in component A	198
Table CS.13. Results for component C (IPS).....	199
Table CS.14. GHG mitigation in component C (IPS).....	200
Table CS.15. Results for component C (IPS).....	200
Table CS.16. GHG mitigation in component C (FLS)	202

List of boxes

Box 5.1. Auctions (example 1) – Estimating technical potential for the assessment period for a tender policy with a partial policy cap.....	35
Box 5.2. Auctions (example 1) – Using policy design characteristics to refine expected RE addition of the policy for the assessment period	38
Box 5.3. Energy market structures and price concepts.....	40
Box 5.4. Auctions (example 1) – Using financial factors to refine expected RE addition of the policy for the assessment period	46
Box 5.5. Auctions (example 1) – Accounting for other barriers to refine expected RE addition of the policy for the assessment period	53
Box 6.1. Example of GHG Reduction Estimation Using Emissions Trajectories	73
Box 6.2. Example of calculating GHG impacts for a tender policy	80
Box 7.1. Example: Ex-post estimation of the GHG impacts of a RE policy	84
Box 5.C1. Hierarchy of RE potential – IPCC definitions	129
Box 5.C2. FiT (example 2) – estimating technical potential for the assessment period for a FiT policy without a policy cap.....	130
Box 5.C3. Net metering (example 3) – estimating technical potential for the assessment period for a net metering policy without a policy cap	130
Box 5.C4. VRE integration with grid-battery storage (example 4) – estimating technical potential for the assessment period for a VRE integration with grid-battery storage policy without a policy cap	131
Box 5.C5. FiT (example 2) – using policy design characteristics to refine expected RE addition for the assessment period	133
Box 5.C6. Net metering (example 3) – using policy design characteristics to refine expected RE addition for the assessment period.....	134
Box 5.C7. VRE integration with grid-battery storage system (example 4) – using policy design characteristics to refine expected RE addition for the assessment period.....	135
Box 5.C8. FiT policy (example 2) – using financial factors to refine expected RE addition of the policy for the assessment period	136
Box 5.C9. Net metering policy (example 3)– using financial factors to refine expected RE addition of the policy for the assessment period	137

Box 5.C10. VRE integration with grid-battery storage policy (example 4) –
using financial factors to estimate impact on technical potential of the policy
for the assessment period 137

Box 5.C11. FiT (example 2) – accounting for other barriers to refine expected RE 139

Box 5.C12. Net metering (example 3) – accounting for other barriers to refine expected RE 141

Box 5.C13. VRE integration with grid- battery storage (example 4) –
accounting for other barriers to refine expected RE addition 143

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A photograph of several white wind turbines with three blades each, situated on rolling green hills. The scene is captured during sunset or sunrise, with a warm, orange and pink sky. A dirt path winds through the hills. In the background, there are more hills and a small town visible in the distance.

Introduction

Chapter 1:

Introduction

[1.1 Purpose and scope of the guide](#) | [1.2 Overview of guide structure](#) | [1.3 A step-by-step approach to using the guide to assess renewable energy policies](#)

This guide provides a methodology for assessing the greenhouse gas (GHG) impacts of selected renewable energy (RE) policies, and forms part of the Initiative for Climate Action Transparency (ICAT) series of policy assessment guides.



Before using this guide, users should first consult the [ICAT Introductory Guide](#), which provides key definitions, core concepts and the overarching framework for applying ICAT GHG impact assessments.

1.1. Purpose and scope of the guide

According to the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report, the energy sector remains the largest contributor to global GHG emissions, particularly carbon dioxide (CO₂), and deep emissions reductions in this sector are critical to limiting the rise in global temperatures (Shukla et al., 2022). The IPCC emphasizes that, to stay on track with the 1.5°C temperature goal, global CO₂ emissions must reach net zero by the early 2050s; for pathways consistent with limiting warming to 2°C, net zero would need to be achieved by the early 2070s. Recent assessments indicate that continued emissions from the energy system risk locking in long-term climate impacts and undermining achievement of the Paris Agreement goals.

Global RE deployment has accelerated dramatically over the past decade, with the International Energy Agency (IEA) reporting the fastest expansion in more than 30 years, with significant implications for global GHG emissions. Global renewable capacity has more than doubled since 2015, driven largely by rapid solar and wind deployment. By 2030, the IEA projects that around 5,500 gigawatts

(GW) of new renewable capacity could be added globally – approximately two-thirds more than previously expected (Hevia-Koch et al., 2023; Abdelilah et al., 2024). This rapid expansion highlights the substantial potential of RE to reduce GHG emissions by displacing fossil fuel-based electricity generation and supporting the electrification of end-use sectors. Despite this progress, global CO₂ emissions from the energy sector have reached record levels in recent years, reflecting continued growth in energy demand and the ongoing reliance on fossil fuels across electricity generation, industry and transport (Abdelilah et al., 2024). RE is nevertheless expected to play a central role in emissions reductions over the coming decades. Under the IEA's Net Zero Emissions by 2050 Scenario, the expansion of RE – particularly wind and solar power – is projected to be the primary driver of CO₂ emission reductions through 2030 and beyond, supported by electrification and improvements in energy efficiency (Hevia-Koch et al., 2023; Abdelilah et al., 2024). Governments therefore have a critical opportunity to close the implementation gap between current emissions trajectories and Paris-aligned pathways by aligning national actions with global climate objectives. A major contribution to further advancing the goals of the Paris Agreement and bridging the emissions gap could come from establishment of ambitious, well-defined and actionable RE targets and policies, including through nationally determined contributions (NDCs) under the Paris Agreement. Parties are requested to submit new or updated NDCs every five years.

Recent updates to the NDC Synthesis Report (United Nations Framework Convention on Climate Change [UNFCCC], 2025) indicate growing participation in the latest round of

submissions. As of November 2025, a total of 86 new or updated NDCs had been submitted by 113 Parties and recorded in the UNFCCC NDC registry between January 2024 and November 2025, representing approximately 69 per cent of global GHG emissions in 2019. Based on these updated NDCs, total global GHG emissions in 2035 are projected to be around 12 per cent below 2019 levels when including land use, land-use change and forestry (LULUCF) (UNFCCC, 2025). While this represents a significant improvement compared with projections prior to the Paris Agreement – when global emissions were expected to increase by between 20 and 48 per cent by 2035 – the latest synthesis assessment indicates that the aggregated effect of current NDCs remains insufficient to place global emissions on a pathway consistent with limiting warming to 1.5°C. This highlights the continued need for strengthened national planning, implementation and accountability mechanisms, including through more ambitious RE targets and policies (Olhoff et al., 2024; UNFCCC, 2025).

Achieving a successful energy transition will require a comprehensive policy mix – not only policies that directly support RE deployment, but also broader measures to improve energy system efficiency, enable grid integration, and ensure that the transition is equitable and inclusive (Al-Zoghoul et al., 2024). In this context, it is essential to assess the GHG impacts of RE policies in a consistent and transparent manner, and to evaluate whether such policies are effectively contributing to national and global climate objectives.

The ICAT Renewable Energy Methodology assists policymakers in evaluating and enhancing the effectiveness of RE policies and provides essential information for preparing reports under the Paris Agreement's enhanced transparency framework (ETF).

This guide sets out the principles, concepts and detailed procedures for estimating the GHG impacts of five key types of RE policies:

- Feed-in tariff (FiT) policies (including feed-in premiums)

- Auction policies (including tender policies)
- Tax incentive policies
- Net metering policies
- Variable renewable energy (VRE) integration with grid-battery storage policies.

This guide can be used at various stages of the policy design and implementation cycle, including:

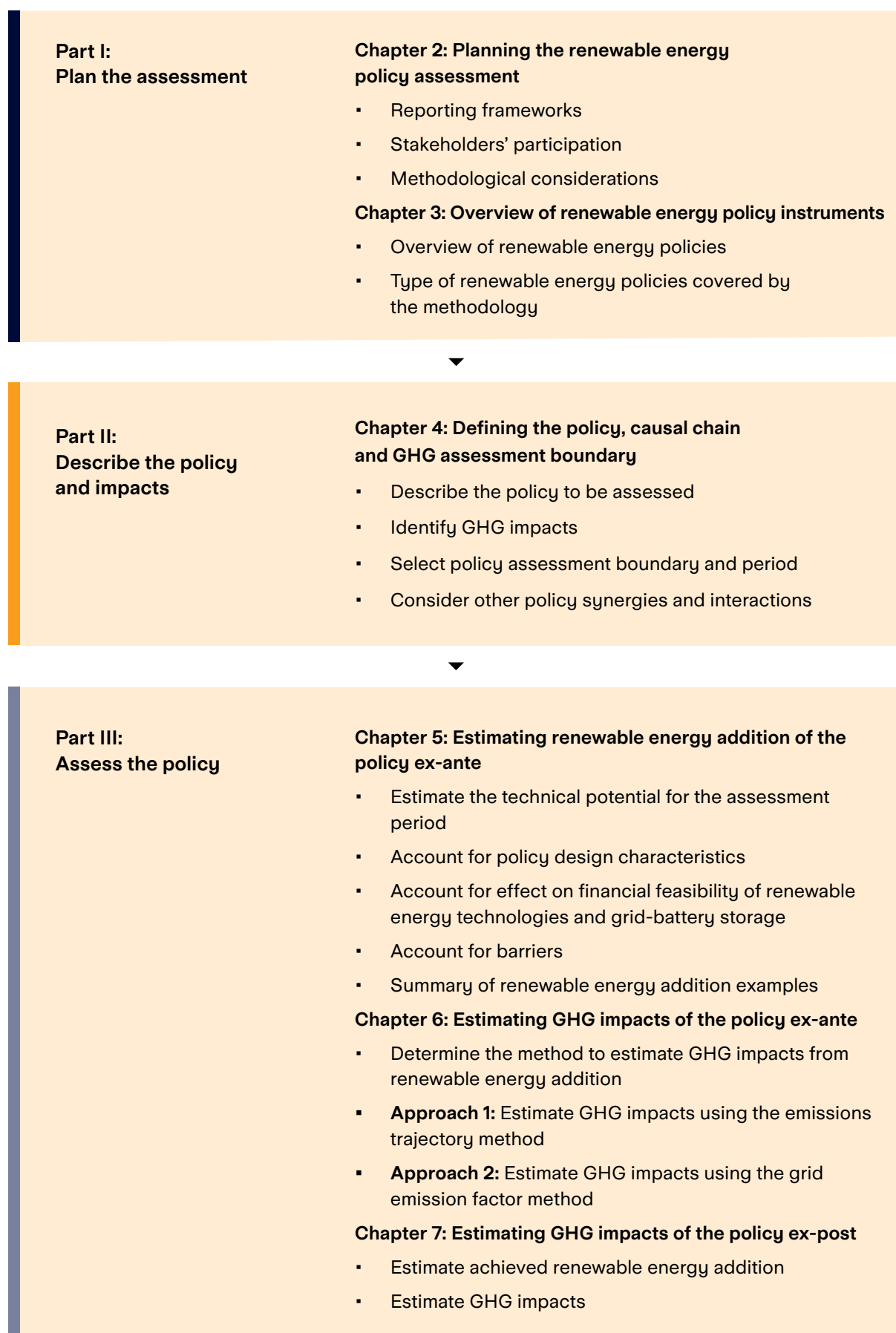
- **Before policy implementation**, to estimate expected future impacts of the policy (ex-ante assessment)
- **During policy implementation**, to assess achieved impacts, monitor key performance indicators (KPIs) and assess expected future impacts (ex-ante and ex-post)
- **After policy implementation**, to assess the actual impacts resulting from the policy (ex-post assessment)

Users can apply the methodology for ex-ante assessment, ex-post assessment or both, depending on their objectives and timing. The most thorough approach applies the methodology before implementation, at intervals during implementation – supporting policy adjustments and fine-tuning – and after implementation, to assess how the policy goals were met at the end of a given implementation period.

1.2. Overview of guide structure

This guide outlines the steps for conducting a GHG impact assessment of RE policies, as illustrated in figure 1.1. The guide is organized into three parts:

Part I – Plan the assessment: Chapter 2 provides a brief overview of reporting frameworks, stakeholder engagement, policy objectives and methodological considerations relevant to the RE sector. Chapter 3 helps users in identifying RE policies applicable to their context, including an overview of policy types and the scope of the methodology. For more detailed guidance on planning the assessment, users are encouraged to refer to Part II of the [ICAT Introductory Guide](#).

Figure 1.1. Structure of the guide

Part II – Describe the policy and impacts:

Chapter 4 supports users in clearly describing the selected policy, outlining its activities, identifying intermediate effects and potential GHG impacts, developing a causal chain, defining the assessment boundary and period, and considering interactions with other policies.

Part III – Assess the policy: Chapters 5–7 present the core methodology for assessing RE policies, including steps to estimate RE addition, GHG impacts (ex-ante and ex-post) and the cost of policy implementation.

The guide also includes supporting materials – such as appendices, case studies, templates, a technical supplement and a toolkit – to support the application of the methodology.

Assessment toolkit: This guide references a range of tools and resources that can support users in conducting the assessment. These tools provide additional guidance, data sets and calculation support for estimating key parameters required in the analysis.

Case studies: The guide includes case studies that illustrate the application of the methodology in selected national contexts and for specific RE policies. These examples provide snapshots highlighting key results, country-specific contexts and methodological considerations while the end-to-end example in [Appendix E](#) represents full application of the guide for a hypothetical case.

1.3. A step-by-step approach to using the guide to assess renewable energy policies

Users can refer to the quick start guide in figure 1.2 for an overview of the assessment process.

Figure 1.2. A step-by-step approach to using the ICAT Renewable Energy Methodology to assess RE policies and actions

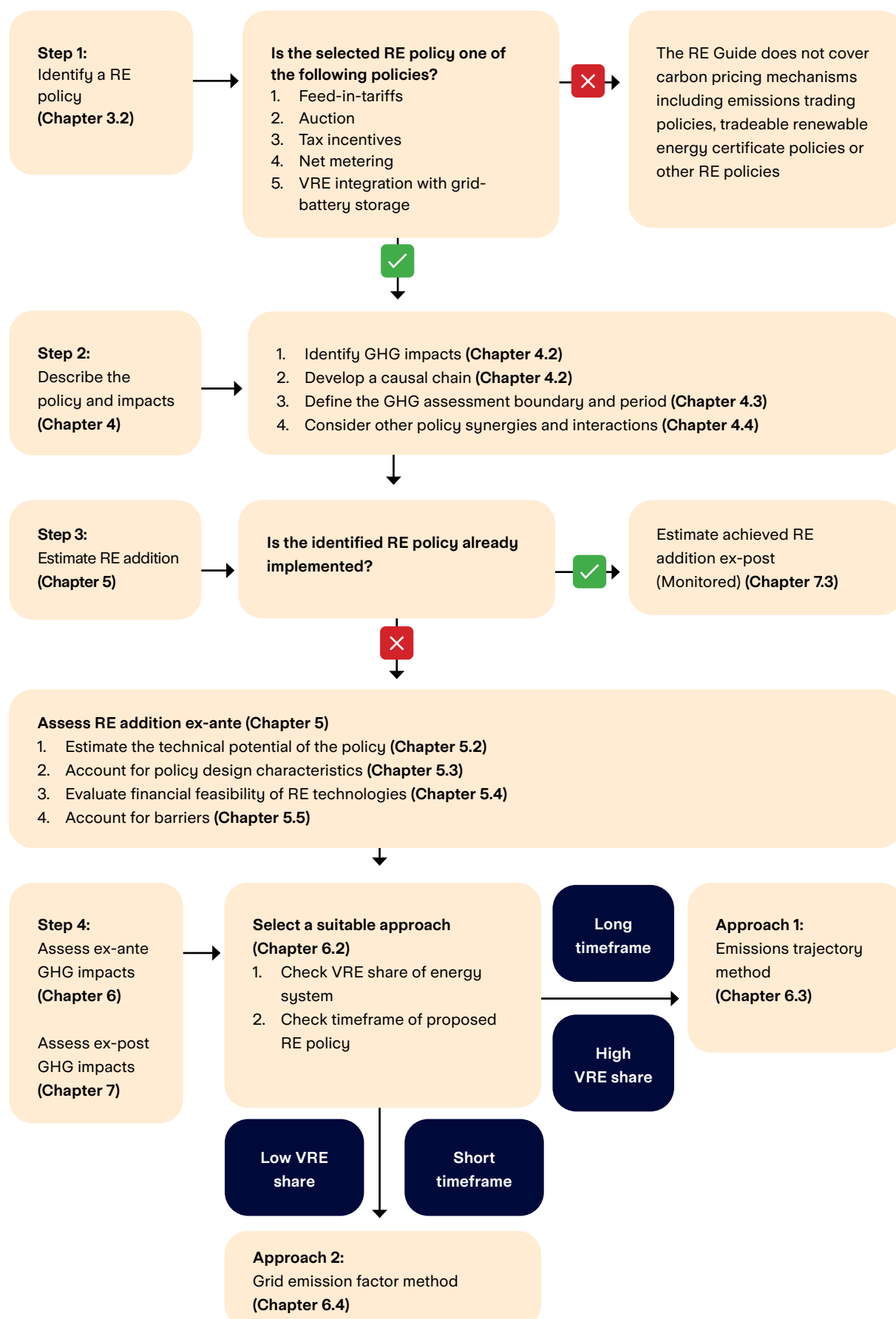


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Part I: Plan the assessment

Chapter 2:

Planning the renewable energy policy assessment

[2.1 Reporting frameworks](#) | [2.2 Stakeholder participation](#) | [2.3 Setting objectives for policy assessment](#) | [2.4 Methodological considerations](#)

Planning a policy assessment involves setting objectives, understanding assessment quality principles, aligning with reporting frameworks, engaging stakeholders, and becoming familiar with key assessment concepts, methodologies, data needs, implementation tracking and technical review processes. These elements are covered in detail in Part II of the [ICAT Introductory Guide](#).



A [template](#) is provided to compile and report assessment results, which can also be used for UNFCCC reporting.

Users should first consult the [ICAT Introductory Guide](#) before using this guide.

The Introductory Guide provides the common framework, key concepts and methodological principles that apply to all ICAT GHG policy assessments. Building on this foundation, this chapter highlights considerations specific to RE policies, including sector-relevant data, methodological choices and examples. Where broader guidance is required – such as on reporting frameworks, stakeholder engagement, assessment quality principles and technical review – users should refer to the ICAT Introductory Guide and other relevant ICAT guides.

2.1. Reporting frameworks

The reporting frameworks relevant to ICAT policy assessments are described in detail in chapter 7 of the ICAT Introductory Guide.

Briefly, table 2.1 explains how the ICAT GHG impact assessment guides align with the ETF and how applying these guides can support reporting in common tabular format (CTF) table 5 on mitigation policies and measures, actions and plans, including their estimated or

achieved GHG emission reductions, related to implementing and achieving NDCs under Article 4 of the Paris Agreement. This can facilitate tracking of NDC implementation and progress. Further details are provided in the ICAT Introductory Guide section 7.1 on “Monitoring performance over time”. Table 2.1 indicates where the information relevant for CTF Table 5 can be found in this Guide.

In addition to GHG impacts, countries may report information on costs, non-GHG mitigation benefits, and interactions between mitigation actions and other policies, where relevant (UNFCCC, 2019). While these elements are not mandatory components of the ICAT Renewable Energy Methodology, this guide provides supporting resources through its assessment [toolkit](#) and cross-references to other ICAT guides – such as the [Sustainable Development Methodology](#) – to facilitate broader evaluations where required.

2.2. Stakeholder participation

Stakeholder participation is recommended at several stages of the assessment process, as it can improve the quality, transparency and credibility of the impact assessment. This guide highlights opportunities for stakeholder engagement at relevant steps. General guidance on stakeholder engagement and participation is provided in the ICAT Introductory Guide (section 4.3), with more detailed practical guidance available in the [ICAT Stakeholder Participation Guide](#).

2.3. Setting objectives for policy assessment

It is important to define the objective of the assessment before applying the methodology.

Common objectives include estimating impacts before policy implementation (ex-ante), during implementation (either ex-ante or ex-post), or after policy implementation (ex-post) to track GHG impacts, enable course corrections and evaluate overall policy effectiveness. The process for setting objectives is described in detail in the [ICAT Introductory Guide](#) (section 4.4).

calculation approaches before conducting an impact assessment. These include, for example baseline and policy scenarios, GHG emissions estimation methods, performance indicators for tracking progress, and reporting and verification considerations. These concepts are explained in detail in the ICAT Introductory Guide (section 4.5) which provides the methodological foundation for all ICAT policy assessment guides.

2.4. Methodological considerations

Users should become familiar with key assessment concepts, data requirements and

Table 2.1. Mapping of UNFCCC CTF Table 5 reporting elements to sections of this guide

UNFCCC mitigation reporting component	Where to find this information in the guide
Name	4.1 Describe the policy to be assessed
Description	4.1 Describe the policy to be assessed
Objectives	4.1 Describe the policy to be assessed
Type of instrument	4.1 Describe the policy to be assessed
Status of policy implementation (e.g., planned, adopted, implemented)	4.1 Describe the policy to be assessed
Sector(s) affected	4.1 Describe the policy to be assessed 4.2 Identify GHG impacts and develop the causal chain
Gases affected	4.2 Identify GHG impacts and develop the causal chain
Start year of implementation	4.3 Define the GHG assessment boundary and period
Implementing entity or entities	4.1 Describe the policy to be assessed
Estimates of expected and achieved GHG emission reductions (gigagrams of CO₂ equivalent [Gg CO₂e])	6.3 Approach 1: Estimate GHG impacts using emissions trajectory method 6.4 Approach 2: Estimate GHG impacts using grid emission factor (GEF) method 7.4 Estimate GHG impacts

Chapter 3:

Overview of renewable energy policy instruments

3.1 An overview of renewable energy policies | 3.2 Type of renewable energy policies covered by the methodology

This chapter provides guidance on identifying and defining RE policies to be assessed. A well-defined policy or action forms the cornerstone of a robust impact assessment, ensuring that its scope, objectives and expected outcomes are transparent and aligned with broader climate and development goals.

The chapter outlines the range of RE policy instruments that fall within the scope of this guide and supports users in determining how their specific policy context fits within it. It then provides a detailed description of the five types of policies covered by the ICAT Renewable Energy Methodology.

3.1. An overview of renewable energy policies

RE policies can be designed to address barriers to the development and deployment of RE technologies, or to promote technological innovation and facilitate faster and more efficient implementation. Such policies may target different stages of the energy value chain and vary in their objectives, design features and implementation approaches.

Table 3.B1 in [Appendix B](#) provides an overview of key policy instruments implemented in the energy supply sector by both developed and developing countries, based on data from the Renewables 2021: Global status report published in 2021 (Renewable Energy Policy Network for the 21st Century [REN21], 2021).

The ICAT Renewable Energy Methodology provides detailed GHG impact assessment approaches for selected policy types, introduced in section 3.2. These policy types have been selected based on their wide-spread use in developing countries.

Depending on national circumstances, RE policies may be designed and implemented by regulatory agencies, public utilities or other government entities. Civil society and private sector actors often also play a significant role in shaping and supporting these policies.

RE investments typically involve project developers and investors who build generation facilities (e.g., solar or wind power plants) and sell the electricity produced. These projects must connect to electricity transmission and distribution networks (the power grid) and receive revenues through electricity markets or contractual arrangements with electricity buyers such as utilities or large consumers. RE policies help create the conditions that enable such investments and the integration of renewable electricity into the power system.

Key design elements of RE policies often include (Edenhofer et al., 2012):

- Enabling investors to recover project costs and earn a return that reflects the level of investment risk
- Ensuring access to electricity transmission and distribution networks (the power grid) and electricity markets for RE producers
- Providing long-term revenue certainty, for example through contracts for the sale of electricity or price guarantees
- Accommodating a diversity of RE technologies and applications
- Adjusting incentives over time as technologies and markets mature while maintaining predictability for investors
- Enabling broad participation of different market actors

3.2. Type of renewable energy policies covered by the methodology

The ICAT Renewable Energy Methodology focuses on a limited set of policy types for which robust and transparent methodologies for estimating GHG impacts can be applied.

The policies covered are described below:

1. FiT policies are price-based instruments that offer a fixed, guaranteed electricity price or a fixed or fluctuating price premium to RE producers.
2. Auction and tender policies are quantity-based instruments that define a targeted volume of RE generation, allowing the market to determine the price through competitive bidding.
3. Tax incentive policies improve the financial viability of RE investments by leveraging the tax system.
4. Net metering policies enable small-scale RE producers, such as households and businesses, to offset their electricity consumption by feeding surplus power into the grid, typically receiving credit on their electricity bills.
5. Policies supporting VRE integration, such as grid-battery storage incentives, support the deployment of storage systems that enhance grid flexibility, and facilitate the integration of VRE sources such as solar and wind.

These policies may be technology-neutral, applying to multiple RE technologies, or technology-specific, targeting particular technologies through eligibility criteria.

This guide does not cover other RE promotion policies, such as carbon pricing instruments (e.g., carbon taxes or emissions trading systems) or renewable portfolio standards and related green power certification schemes that may use TRECs.

A detailed description of the policy selection approach and criteria is provided in [Appendix B](#).

3.2.1. Feed-in tariff policies (including feed-in premiums)

FiT policies help promote RE by guaranteeing that power producers can sell the electricity they generate at a fixed price for a long period, often 15–20 years. This provides producers with financial stability and predictability, and therefore encourages investment.

This methodology can also be applied to feed-in premium policies, which provide renewable electricity producers with an additional payment on top of the price they receive for the electricity they generate. These premiums may be fixed or vary depending on electricity prices. Similar to FiTs, feed-in premiums typically involve long-term payment arrangements that help reduce revenue uncertainty and financial risk for investors.

FiTs and premiums have worked well around the world to support many types of RE, such as wind, solar PV, solar thermal, geothermal, biogas and biomass. They have supported both small and large projects, and encouraged the use of different technologies.

Successful FiT and premium policies often include (Edenhofer et al., 2012):

- Eligibility for different types of renewable electricity producers
- Long-term payment arrangements that allow investors to recover project costs and earn a reasonable return
- Payment levels reflecting the cost of generating electricity from different RE technologies and project sizes
- Guaranteed access to electricity transmission and distribution networks
- Arrangements requiring designated electricity buyers to purchase renewable electricity
- Periodic reviews of policy design and payment levels

3.2.2. Auction policies (including tender policies)

Auction policies are used by Governments to promote RE by encouraging competition among project developers. In this guide, “auction policies” refers to both auctions and tenders.¹

Auction and tender policies are both competitive policy tools used by Governments to support RE deployment, but they differ in how competition is structured, what is being competed for and how prices are determined.

Under these policies, Governments invite companies to submit bids to develop RE projects. Bids may be based on the total investment cost of a project or the price per unit of electricity generated. Auctions typically involve an open bidding process, whereas tenders are often conducted through confidential submissions. In both cases, the Government sets a target for the total capacity of RE projects to be developed, and awards contracts to the most competitive bids until this target is met.

The design of auction and tender policies involves balancing multiple considerations that influence competition, participation and outcomes:

- **Demand and technology scope:** Governments may choose between technology-specific auctions, which target particular RE technologies (such as solar or wind), and technology-neutral auctions, which allow different technologies to compete. This choice can affect the diversity, cost-effectiveness and system integration of the resulting energy mix.
- **Qualification requirements:** Entry criteria (e.g., financial capacity, technical experience or project development readiness) should ensure project feasibility and timely delivery, while avoiding overly restrictive requirements that discourage participation, particularly from smaller or local companies.

- **Winner selection process:** Transparent and simple selection rules help build investor confidence, while additional criteria may be used to support broader policy objectives, such as innovation, local economic development or system reliability.
- **Risk allocation:** The allocation of risks between governments and developers – including price, currency and delivery risks – can strongly influence participation and project implementation. Excessive risk placed on developers may discourage competitive bidding or increase project failure rates.

To promote a diverse and inclusive RE market, policymakers may consider additional auction design elements, such as:

- Measures to prevent market concentration, including caps on the volume awarded to a single bidder
- Long-term schedules of periodic auctions, which provide visibility and predictability for investors and supply chains
- Segmented auctions, with dedicated bidding windows or volumes for smaller, local or new market participants
- Local content or local participation provisions, where appropriate, combined with complementary incentives (such as preferential financing terms or fiscal measures)
- Currency-related design features, such as local currency denomination or indexation mechanisms, to reduce foreign exchange risk in relevant contexts

By carefully designing auction and tender policies and considering these elements, Governments can effectively scale up RE deployment while promoting competition, market development and broad participation.

The ICAT Renewable Energy Methodology becomes applicable once renewable electricity generation supported by these policies is connected to the grid and begins producing electricity.

1. For a comprehensive guide to auction policy design, see Ferroukhi et al. (2015).

3.2.3. Tax incentive policies

Various types of tax incentive policies are available for the development and deployment of RE technologies. Many Governments use tax policies to promote RE sources for electricity generation. Types of tax incentives include:

- Exemptions from VAT
- Income tax exemptions
- Tax reductions on imported or exported equipment and materials
- Sales tax exemptions
- Accelerated depreciation
- Property tax reductions or exemptions
- Tax credits
- Exemptions from local or municipal taxes
- Reductions or exemptions from RE-specific taxes (e.g., geothermal vapour or surface taxes)
- Other fiscal benefits

Tax incentives usually apply to services and equipment. Pre-investment expenses are related to RE projects, as well as income from the sale of electricity or other ancillary income. Policymakers can further opt for fiscal stability incentives, whereby eligible RE technologies are shielded from potential future changes in the fiscal regime or any additional fees. Tax incentive policies can be more effective when linked to the generation of electricity, and not just the installation of capacity. Different levels of government (national, subnational or municipal) may intentionally implement overlapping tax incentive policies simultaneously.

3.2.4. Net metering policies

Net metering is a type of contract that binds a self-generating customer to the energy

distributor. In this contract, the customer is both a consumer and a producer of electricity (for example, small-scale RE systems such as rooftop solar PV installations). When a customer has excess electricity that they have generated on-site but not used, then this and surplus electricity may be injected into the grid and credited to the customer's electricity account according to the applicable regulatory framework. In traditional net metering schemes, this crediting typically occurs at the retail electricity rate within a defined billing period. The customer benefits from a reduced electricity bill through self-consumption of the electricity produced on-site, as well as sales of electricity back to the grid (Roux and Shanker, 2018). However, various forms of net metering exist, and the nuances among them can lead to differing implications. For example, cost shifting in electricity net metering arises when customers with rooftop solar are credited for exported electricity at the full retail rate, rather than a rate reflecting its actual value to the grid.²

To address these concerns, several net metering-related or alternative compensation schemes have been developed, including net metering plus, net metering with caps, and time-of-use (TOU)-based compensation mechanisms:

- **Net metering plus** provides credits to consumers at a rate lower than the retail price, ensuring that fixed costs are partially recovered by utilities.
- **Net metering with a cap** limits the total capacity or volume of energy eligible for crediting under net metering, either as a fixed capacity limit or a percentage of total electricity generation. Once the capacity cap is reached, new participants may no longer be eligible. Similarly, if the cap is defined as a percentage of total electricity generation, electricity exported beyond this limit is not credited.

2. Retail electricity tariffs typically recover not only energy costs, but also fixed costs for transmission, distribution and maintaining grid reliability. When net-metered customers offset their electricity bills at the retail rate, they may avoid paying their share of these fixed costs, while still relying on the grid for backup power. As a result, utilities may need to recover these costs from a smaller base of customers, potentially shifting costs to non-participating consumers.

- **TOU-based compensation mechanisms** apply different credit values depending on the time of electricity export. Consumers earn higher credits for exporting electricity during peak demand periods and lower credits during off-peak times.

Where compensation for exported electricity differs from the retail electricity rate, these arrangements are more accurately described as **net billing** or **feed-in-type mechanisms**, rather than traditional net metering.

These variations aim to improve the financial sustainability of distributed generation policies while maintaining incentives for investment. As such, the implementation of net metering and related schemes requires careful regulatory design to balance the interests of self-generating customers, utilities and non-participating consumers.

Net metering is particularly important because it has been adopted in a large number of countries, including many developing countries that are expanding grid infrastructure while promoting decentralized electricity generation. In 2022, net metering or similar arrangements were in place in at least 44 developing countries. The ICAT Renewable Energy Methodology becomes applicable once decentralized renewable electricity generation is connected to the grid.

Net metering plays a crucial role in promoting RE adoption by enabling small-scale generation, particularly solar PV systems, more economically attractive. It encourages households and businesses to invest in clean energy technologies and distributed generation.

3.2.5. Variable renewable energy integration with grid-battery storage policies

VRE cannot be dispatched on demand, posing challenges for grid stability and energy reliability. VRE integration with the grid is therefore crucial to move towards use of RE resources such as wind and solar. VRE integration can be achieved in several ways, such as VRE with battery storage, pumped hydro storage, demand response through

smart grids, green hydrogen storage (using excess VRE), regional grid connectivity, etc. Battery storage can play a vital role in integrating VRE sources like wind and solar, ensuring that the grid can absorb and use the excess intermittent energy and thus enhance grid reliability and stability. The storage of excess renewable electricity for later use helps maximizing the GHG reduction potential from RE use.

Battery storage promotion policies include a variety of policies, including:

- Financial incentives and subsidies
- TOU pricing that may encourage utilities or third-party operators to profit from arbitrage
- Facilitating measures such as grid interconnection standards
- Regulatory and market reform policies such as storage mandates, ancillary service provisions and other supportive mechanisms

In developed markets with high renewable penetration, it could also include regulatory and market reform policies such as energy storage mandates and participation in capacity markets. It should be noted that battery storage can also be promoted at consumer level, but here only grid-level (i.e., utility-scale) battery storage policies have been covered.

Battery storage can be implemented through a variety of business models (Eller and Gauntlett, 2017; Ralon et al., 2017; Bowen, Chernyakhovskiy and Denholm, 2019; IEA, 2023a), reflecting different ownership structures, risk allocations and market roles. These models are not necessarily mutually exclusive, and may coexist within the same electricity system. The feasibility and role of different business models depend largely on the structure of the electricity sector, including regulatory frameworks, the role of utilities and the degree of market liberalization.

Utility-owned model

In this model, the utility owns and operates battery storage assets as part of the regulated electricity system. Storage investments are

typically recovered through regulated tariffs, and are often justified on the basis of system reliability, peak shaving or deferral of network upgrades. This model is commonly applied where utilities play a central role in system planning, and where regulatory frameworks allow storage to be treated as a grid asset.

Independent power producer (IPP)-owned model

Under this approach, private developers finance, build and operate battery storage systems. Revenue is generated by selling energy, capacity or ancillary services to utilities through contracts, or by participating directly in electricity markets where permitted. This model relies on clear market signals and contractual arrangements, and is more common in liberalized or partially liberalized power systems.

Co-located with renewables model

Battery storage is installed alongside RE generation facilities, such as solar or wind power plants. Co-location allows storage to shift electricity generation over time, reduce curtailment, smooth output variability, and improve the value of renewable electricity delivered to the grid. This model is increasingly used to support the integration of VRE, and to meet grid connection or dispatch requirements.

Energy storage-as-a-service (ESaaS)

In the ESaaS model, a third-party provider owns, installs, operates and maintains the energy storage system, while the utility or end user pays a fixed fee or service-based charge for access to energy storage capacity and/or defined services. This model reduces upfront capital requirements for utilities or end users, and can support early deployment of energy storage, particularly in contexts where investment capacity or experience with energy storage technologies is limited.

Public-private partnerships (PPPs)

PPP models involve shared investment and risk between public entities and private firms. They can be particularly relevant in countries with limited public financing capacity or higher perceived investment risks. PPPs may

be used to support pilot projects, strategic infrastructure development or storage deployment in underserved regions, with the public sector providing guarantees, co-financing or policy support.

While the co-located model provides a direct link between storage and a specific RE project, the utility-owned, IPP-owned, ESaaS and PPP models act as system-level facilitators. These models are assessed in this guide by their ability to reduce grid integration barriers (as detailed in **chapter 5**), thereby enabling higher levels of RE penetration and reducing the curtailment of clean energy, which leads to measurable GHG reductions (as detailed in **chapter 6**).

Many of these models are in the pilot stage or early deployment stage in a number of countries. Their viability depends on factors such as regulatory frameworks, market design, access to finance and the role assigned to storage within the power system. As experience with battery storage increases and regulatory arrangements evolve, these models are expected to mature and expand, supporting higher shares of variable RE in electricity systems.

Photo by Karsten Wuerth from Unsplash

A photograph of several offshore wind turbines in the ocean under a clear blue sky. The turbines are silhouetted against the horizon. The water is a deep blue with gentle ripples. The sky transitions from a pale blue near the horizon to a deeper blue at the top.

Part II: Describe the policy and impacts

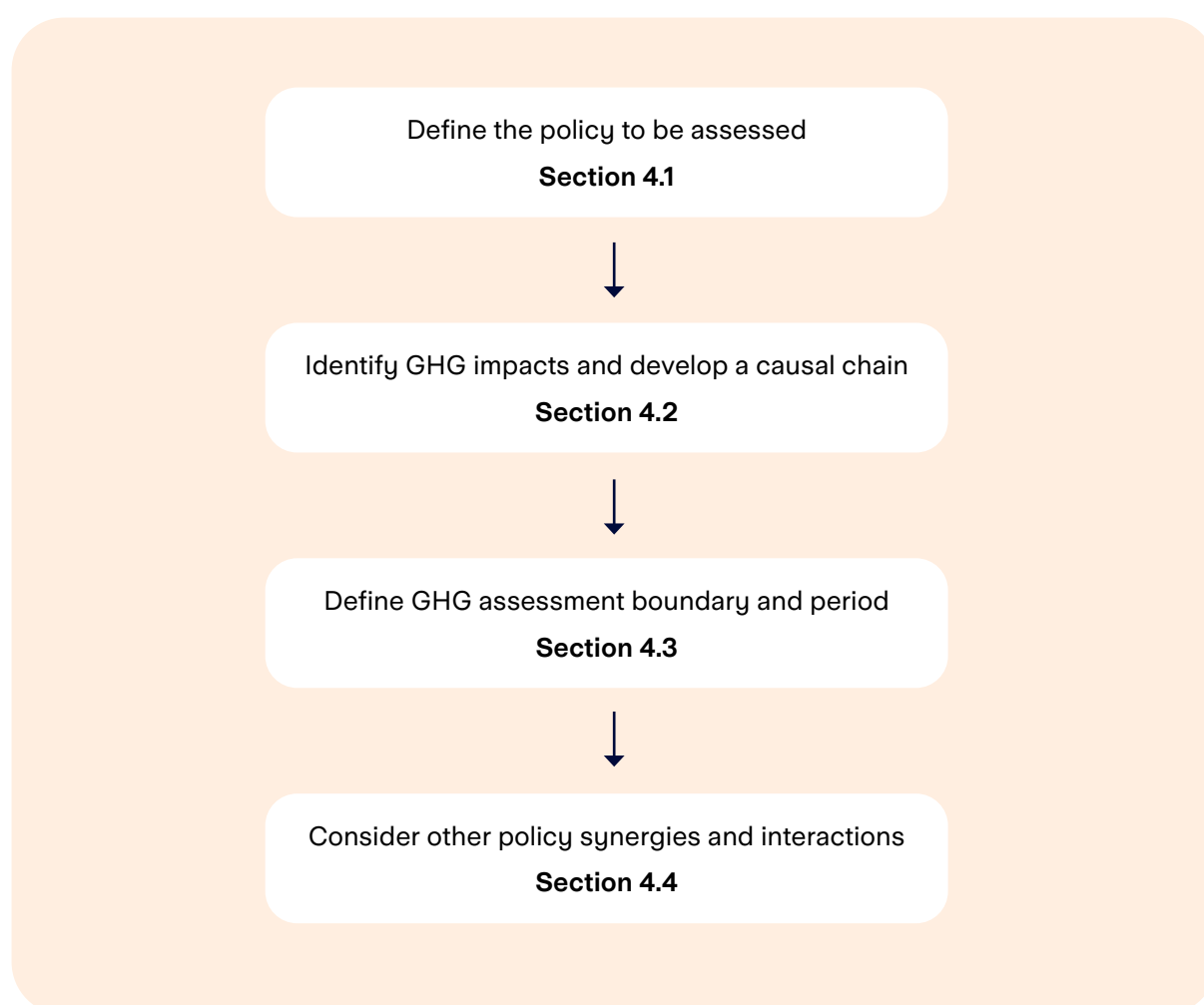
Chapter 4: Defining the policy, causal chain and GHG assessment boundary

[4.1 Define the policy to be assessed](#) | [4.2 Identify GHG impacts and develop the causal chain](#) | [4.3 Define the GHG assessment boundary and period](#) | [4.4 Consider other policy synergies and interactions](#)

This chapter outlines the process for defining the policy under assessment, establishing the causal pathways through which it influences GHG emissions, and determining the appropriate assessment boundary and time frame. It begins by clearly defining the policy and identifying its intermediate effects and potential GHG impacts, before developing a causal chain that links policy actions to emission outcomes. The chapter

then describes how to establish the GHG assessment boundary and assessment period, including the choice between ex-ante and ex-post assessment approaches. Finally, it considers interactions with other policies, and explores how these synergies or trade-offs may influence GHG outcomes, sustainable development objectives and broader transformational change.

Figure 4.1. Overview of steps in the chapter



4.1. Define the policy to be assessed

To effectively carry out an impact assessment (described in subsequent chapters), a detailed understanding of the policy being assessed is needed.



It is a key recommendation to:

- Clearly describe the policy (or package of policies) being assessed.
- Identify all potential GHG impacts and their associated GHG source categories to ensure no significant effects are overlooked.
- Develop a causal chain to map the sequence of cause-and-effect relationships, identifying the intermediate effects that lead to final GHG impacts.
- Define the GHG assessment boundary by including all significant GHG impacts identified during the mapping process.
- Define the assessment period and establishing the time frame over which the policy's impacts will be evaluated.



Tools and methodological approach

To assist in creating a thorough policy description, users should refer to [Appendix A](#), which provides a checklist of essential information and illustrative examples of RE policies. For more complex contexts, [table 4.A2](#) offers additional details that may be relevant for a deeper characterization.

When a policy is part of a larger integrated strategy, these checklists can be used to document the entire package of policies as a single unit or to evaluate each individual

policy separately, depending on the assessment objective.

Users should note that the first two steps of this chapter – defining the policy and identifying impacts – are often iterative, and can be performed together to refine the assessment scope.



A template for completing the policy description is available for download in the Templates section.

4.2. Identify GHG impacts and develop the causal chain

GHG impacts are defined as the net changes in GHG emissions attributable to the implementation of a specific policy. For the majority of RE interventions, the predominant impact is the displacement of emissions from existing fossil fuel-fired power plants, or the prevention of emissions from new fossil fuel capacity that would have otherwise been commissioned.

For such standard interventions, users may leverage the standardized impact identification framework in table 4.4 to enhance assessment efficiency, while maintaining a clear audit trail. However, if a policy involves technologies that generate additional emissions – such as CO₂ or methane (CH₄) from hydropower reservoirs or biomass land-use change – users must follow the comprehensive identification process described in this section to ensure all significant impacts are captured. Although the identification of intermediate effects and GHG impacts is presented as a prerequisite for developing the causal chain, in practice these analytical steps are typically conducted in an integrated or iterative manner to ensure technical accuracy.

4.2.1. Identify policy intermediate effects

To assess the GHG impacts of a policy, it is important to first understand how the policy is implemented. This involves identifying the relevant inputs and activities associated with implementation, and how these contribute to intermediate effects. Users should begin

by identifying the key stakeholders involved, along with the inputs and activities necessary to implement the policy. Table 4.1 provides illustrative examples of stakeholder responses to the implementation of RE policies, which can help identify intermediate impacts arising from policy implementation.



Consultations with stakeholders can help to identify intermediate effects and identify and address possible unintended or negative impacts early on.



Further guidance on identifying intermediate impacts of policies is available in the [ICAT Introductory Guide](#) (section 5.3.1), as this

information is applicable across all ICAT policy assessment guides.

4.2.2. Identify potential GHG impacts



A critical step in the assessment process is identifying all relevant GHG impacts and associated emission source categories. A recommended method for doing so is outlined in the ICAT Introductory Guide (section 5.3.2), with further detail available in the World Resources Institute (WRI) Greenhouse Gas Protocol Policy and Action Standard (Rich et al., 2014) available in this guide's [assessment toolkit](#).

Table 4.1. Examples of stakeholder responses to policy implementation and intermediate effects

Policy implementation components	Stakeholder response examples
Inputs	▪ Access financial incentives such as grants, tax credits or low-interest loans ▪ Establishment of pilot projects or demonstration sites for RE technologies ▪ Provision of technical assistance and capacity-building programmes
Activities	▪ Participate in RE programmes and initiatives ▪ Attend training sessions to enhance knowledge of RE technologies and best practices ▪ Invest in RE equipment and infrastructure ▪ Report energy production and consumption data for monitoring purposes
Intermediate effects	▪ Increased RE installations and power generation (such as hydro, bioenergy) ▪ Optimize energy management strategies to improve efficiency ▪ Implement grid integration measures to enhance energy reliability ▪ Increased system flexibility, reduction in clean energy curtailment and enhanced grid stability (in case of VRE integration and grid-battery storage policies)

Multiple types of GHG impacts should be considered, as summarized in table 4.2. These include direct and indirect emissions across the life cycle of electricity generation technologies. For instance, biomass and large

hydropower projects may result in indirect land-use changes or material displacement impacts. If RE policies promote such technologies, these associated emissions should be accounted for in the assessment.

Table 4.2. Types of GHG impacts

Type of GHG impact	Description	Example
Positive and negative impacts	Impacts that cause decrease or increase in GHG emissions	Positive: Displaced GHG emissions from existing and new fossil fuel power plants. Negative: Increased emissions from manufacturing of RE-based systems/equipment.
Intended impact versus unintended impact	Impacts that are both intentional and unintentional based on the original objectives of the policy	Intended: Avoided GHG emissions from fossil fuel power plants; avoided GHG emissions from national manufacturing of fossil fuel power plant equipment. Unintended: Increased GHG emissions in other jurisdictions; increased GHG emissions from manufacturing of equipment for renewables.
In-jurisdiction impact versus out-of-jurisdiction impact	In-jurisdiction impacts are those that occur inside the geographic area over which the implementing entity has authority, such as a city boundary or national boundary. Out-of-jurisdiction impacts occur outside the geopolitical boundary	In-jurisdiction: Increased GHG emissions from manufacturing of equipment for renewables; avoided GHG emissions from local manufacturing of equipment for fossil fuel power plants. Out-of-jurisdiction: Induced GHG emissions in other jurisdictions (e.g., from electricity generation).
Short-term impact versus long-term impact	Impacts that are both nearer and more distant in time, based on the amount of time between implementation of the policy and the impact	Short-term: Displaced GHG emissions from operating fossil fuel power plants on the electricity grid. Long-term: Avoided emissions from lower energy use due to increased cost of electricity.



The 'Draft Mechanism Methodology: Electricity generation from renewable sources connected to an electricity system' (UNFCCC, 2026), i.e., the PACM, is applicable to greenfield power plants that generate electricity from renewable sources connected to the electricity system, including run-of-river hydro, wind, solar and geothermal power plants. It provides methods to estimate CH₄ emissions from geothermal power plants and other RE projects using backup generators.

potential GHG impacts, taking into account jurisdictional considerations and the role of stakeholder engagement (with additional guidance available in chapter 8 of the [ICAT Stakeholder Participation Guide](#)). In contrast, the ICAT Renewable Energy Methodology offers sector-specific examples in table 4.2 that illustrate types of GHG impacts in relation to jurisdictional scope, policy intent and the longevity of impacts.

Additionally, table 4.3 lists example source categories, which are the same for both RE projects and policies, making them familiar to users with a project background.

The [ICAT Introductory Guide](#) (section 5.3.2) provides further detail on identifying

Table 4.3. Examples of GHG emission sources associated with RE projects and policies

Source category	Description	Emitting entity or equipment	Relevant GHGs
Grid-connected electricity generation	CO ₂ emissions from electricity generation in fossil fuel-fired power plants that are displaced due to the project activity	Grid-connected power plants	CO ₂
Water reservoirs of hydropower plants	CH ₄ and CO ₂ emissions from reservoirs	Decaying organic matter in reservoirs	CH ₄ , CO ₂
Fugitive emissions of geothermal power plants	Fugitive emissions of CH ₄ and CO ₂ from non-condensable gases contained in geothermal steam	Steam from power plant	CH ₄ , CO ₂
Emissions from fossil fuel combustion in RE plants	CO ₂ emissions from combustion of fossil fuels for electricity generation in solar thermal power plants and geothermal power plants	Solar thermal and geothermal power plants	CO ₂

Sources: Dornau et al. (2015); UNFCCC (2018).

Notes:

- Electricity generation from fossil fuels also generates nitrous oxide (N₂O); however, it represents a small fraction of total CO₂-equivalent emissions (less than 1 per cent), and is therefore not considered. In the case of biomass-based electricity generation, it can be higher (around 7 per cent), and should be considered.
- Electricity generation also produces water vapour, which is a GHG. However, water vapour is short-lived in the atmosphere, and it is therefore not included in GHG inventories under IPCC methodologies.



A template is available for download in the [Templates section](#) to help document all policy GHG impacts.

4.2.3. Develop a causal chain

A causal chain is a conceptual tool that maps how a policy leads to GHG impacts through a sequence of cause-and-effect relationships.



Figure 4.2 presents a high-level example for RE policies; however, actual causal chains will vary depending on the specific policy and context. Users are encouraged to develop their own detailed causal chains, and may refer to the [ICAT Introductory Guide](#) (section 5.3.3) and the [Policy and Action Standard](#) (Rich et al., 2014) for further guidance.



Consultations with stakeholders can help with the development and/or validation of the causal chain by integrating stakeholder insights on cause-effect relationships between the policy, behaviour change, and expected impacts.



A template for completing a causal chain diagram is available for download in the [Templates section](#).



The WRI's Policy and Action Standard is available in this guide's [assessment toolkit](#) for additional resources on developing a causal chain.

4.3. Define the GHG assessment boundary and period

4.3.1. Select ex-ante or ex-post assessment

Users should decide whether to conduct an ex-ante, ex-post or combined assessment based on the policy's status and the assessment objective. Additional guidance is available in the [ICAT Introductory Guide](#) (section 5.3.5).

4.3.2. Define the GHG assessment boundary

The GHG assessment boundary defines the scope of GHG impacts included in the assessment.

Geographic and temporal boundaries are also defined for the GHG impacts. For most RE policies (specifically solar and wind), the primary impact is displaced emissions from fossil fuel power generation, as this is typically both very likely and of major magnitude. Users should refer to table 4.4 to ensure each GHG impact is appropriately categorized. Impacts that are of moderate or major magnitude and are very likely, likely or possible should be included within the assessment boundary.



Further guidance on impact categorization is available in the [ICAT Introductory Guide](#) (section 5.3.4) and the [Policy and Action Standard](#) (Rich et al., 2014)



A template for documenting assessment boundary characteristics is available for download in the [Templates section](#).



The WRI's Policy and Action Standard is available in this guide's [assessment toolkit](#) for further guidance on impact categorization.

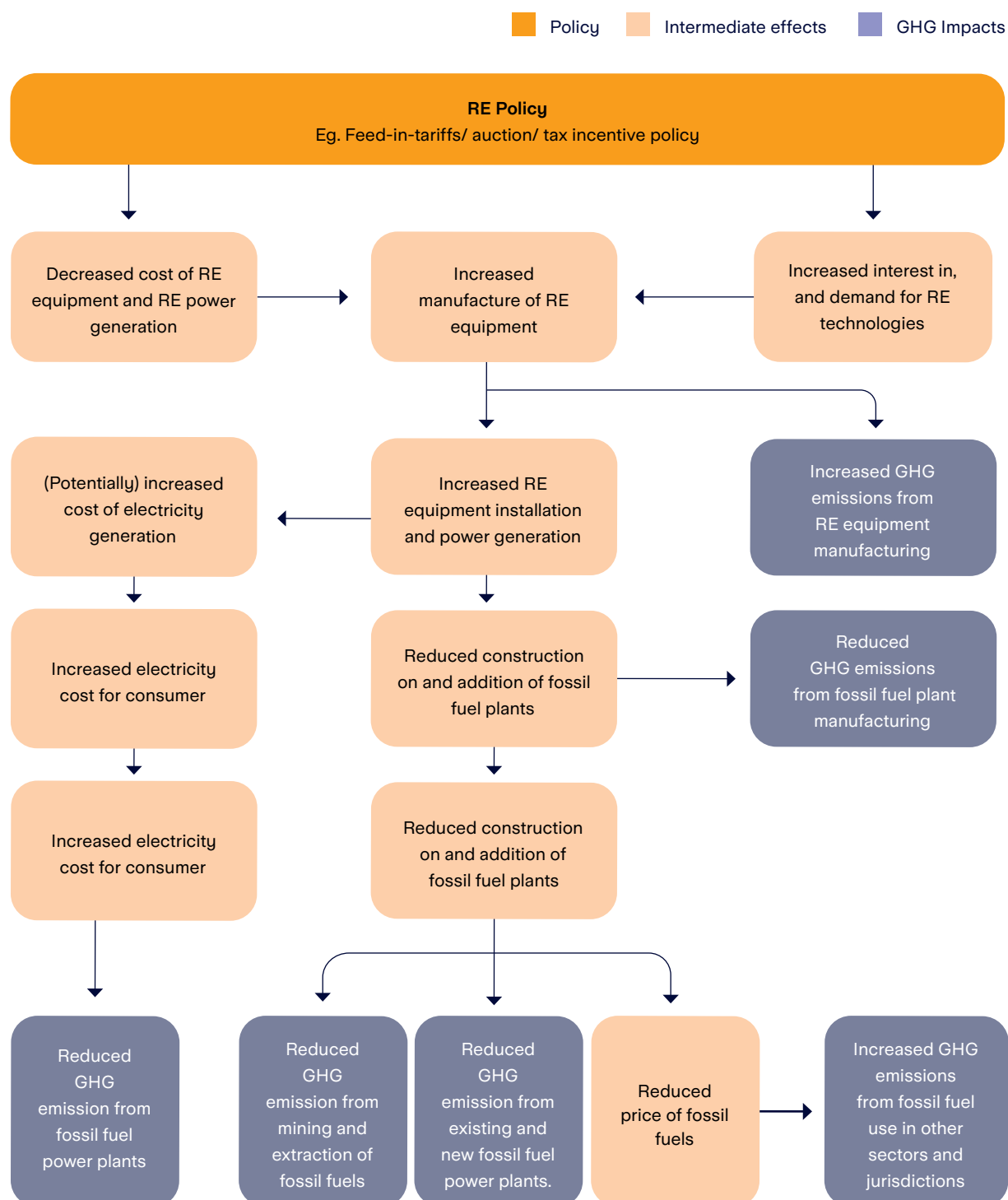
4.3.3. Define the assessment period

The assessment period refers to the time frame over which the GHG impacts of a policy are evaluated. It is a key recommendation to define the assessment period.

Users should consult the [ICAT Introductory Guide](#) (section 5.3.5) for further guidance on establishing an appropriate assessment period.

4.4. Consider other policy synergies and interactions

When multiple policies are developed or implemented within the same time frame, users may assess them individually or as a policy package. This decision should consider the assessment objectives, feasibility of separate versus combined assessment, the scope and strength of policy incentives, and the level of interaction between the policies.

Figure 4.2. Example causal chain for RE policies**Notes:**

- This causal chain diagram is illustrative and presents a range of possible impact pathways. Users should apply only those impacts that are relevant to their specific country and policy context.
- In many countries, RE technologies have already reached, or are approaching, grid parity. This should be reflected in country-specific analyses. In such cases, impacts related to increased electricity generation costs may not be applicable, and the corresponding parts of the causal chain may be excluded.
- The causal chain primarily captures short-term impacts of RE policies. Longer-term impacts – such as renewable electricity becoming fully competitive with fossil fuel-based generation – are addressed indirectly through periodic revisions of baseline assumptions over time, as part of the methodology.

Table 4.4. Example of GHG impacts and emission sources considered in defining the GHG assessment boundary

GHG impact	GHG	Likelihood	Relative magnitude	Included/excluded	Explanation
Displaced GHG emissions from existing and new fossil fuel power plants	CO ₂ CH ₄ N ₂ O	Very likely	Major	Included	The main GHG impact of RE policies. CO ₂ emissions are major emissions. Other two are minor.
Displaced emissions from mining of fossil fuels (upstream emissions and leakages)	CH ₄ CO ₂	Possible	Moderate to major	Optional and encouraged; Often excluded due to data uncertainty	Can be significant in systems with high upstream CH ₄ leakage (e.g., natural gas supply chains). Inclusion is recommended, but exclusion is a conservative choice.
Induced emissions from RE equipment manufacturing and construction	CO ₂ CH ₄ N ₂ O	Possible	Minor	Excluded	These emissions are generally minor compared to displacement; exclusion is a conservative choice.
Avoided emissions from construction of fossil fuel power plants	CO ₂ CH ₄ N ₂ O	Possible	Minor	Excluded	Generally small and typically offsets the emissions from building the new renewable plants.
Leakage emissions to other jurisdictions	CO ₂ CH ₄ N ₂ O	Possible	Minor	Excluded	Considered insignificant for most RE policies.
Avoided emissions from lower energy use due to increased cost of electricity	CO ₂ CH ₄ N ₂ O	Possible	Minor	Excluded	Considered insignificant for most RE policies.
Emissions from geothermal power plants (fugitive emissions)	CO ₂ CH ₄	Possible	Moderate	Included, policy dependent	Significant for RE policies involving geothermal power generation.
Emissions from hydropower plants (reservoir emissions)	CH ₄ CO ₂	Possible	Moderate	Included, policy dependent	Significant for large-scale reservoirs with high organic matter decomposition.

GHG impact	GHG	Likelihood	Relative magnitude	Included/excluded	Explanation
Emissions from biomass power plants (agriculture and land-use change)	CO ₂ CH ₄ N ₂ O	Very likely	Minor to major	Included, policy dependent	The magnitude depends on feedstock source and land-use impacts. Emissions may be significant if the policy induces land-use change or unsustainable biomass harvesting.
Emissions from construction of transmission infrastructure	CO ₂	Possible	Minor	Excluded	Typically small, relative to avoided generation emissions

4.4.1. Types of policy interactions

The combined impact of interacting policies may differ from the sum of their individual impacts if implemented separately.



Further guidance on assessing policy interactions is available in the [ICAT Introductory Guide](#) (section 5.2.1) and the [Policy and Action Standard](#) (Rich et al., 2014). Both resources are available in this guide's [toolkit section](#).

In the RE sector, policy interactions should be assessed in relation to both other RE policies and the broader energy policy framework. RE policies are often part of integrated energy strategies, such as those combining fossil fuel plant decommissioning, nuclear phase-out and renewable deployment. For example, a tender process for RE may include periodic windows where capacity caps are adjusted based on the progress of related measures like fossil fuel retirement or nuclear phase-out. Such interactions influence the timing and extent of RE deployment.

4.4.2. Identification of interaction between policies

If a user decides to assess a package of interacting policies, based on their specific objectives and circumstances, two main steps should be followed:

- **Step 1:** Characterize the type and degree of interactions between the policies.
- **Step 2:** Undertake a preliminary analysis to understand the nature of these interactions and determine whether to assess individual policies or a policy package.

Users may refer to the ICAT Introductory Guide (section 5.2.1) for further details on the steps outlined above, including criteria for determining whether to assess an individual policy or a policy package, as well as guidance on the overlap and reinforcement of incentives provided by different policies.

Table 4.5 provides an example of how RE policies targeting the same GHG emissions sources can interact. In this case, a FiT for wind-based power generation is assessed in relation to multiple other policies and actions that also target emissions from fossil fuel combustion in grid-connected power plants. The table illustrates the types and degrees of interaction between these policies.

4.4.3. Impact on sustainable development and transformational change

RE policies contribute to a wide range of sustainable development impacts beyond GHG reductions. These include improvements

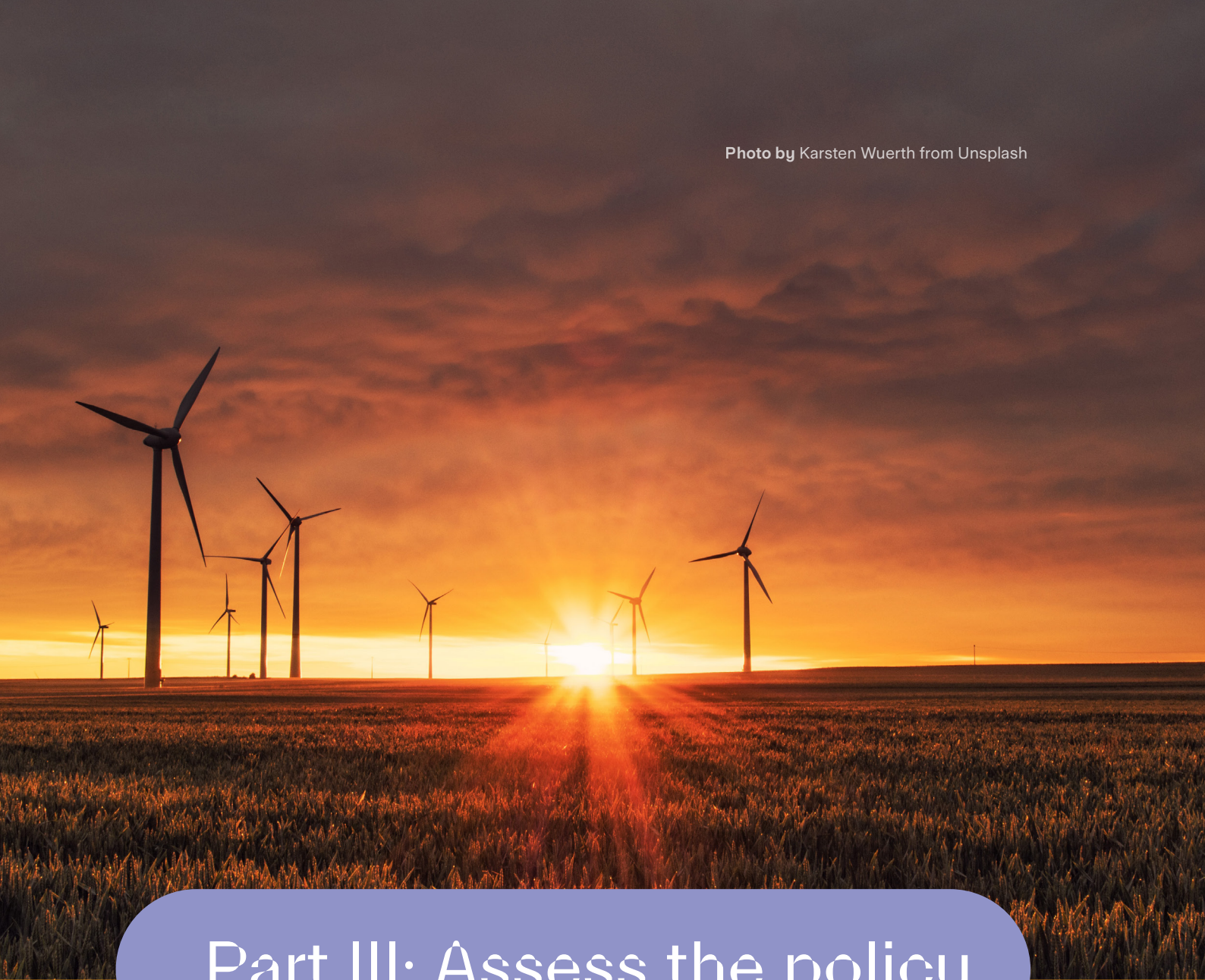
Table 4.5. Example of mapping policies that target the same emissions sources

Policy being assessed	Target emission source(s)	Other policies/actions targeting the same source	Type of interaction	Explanation
FiT for wind-based power generation	Fossil fuel combustion in grid-connected power plants	Subsidy on power plant equipment	Overlapping	Moderate
		RPS mandate	Overlapping	Major
		Excise duty exemption on power plant equipment parts	Overlapping	Minor

Source: Adapted from Dornau et al. (2015).

in environmental, social and economic conditions – such as increased economic activity, job creation, enhanced public health, better air quality and greater energy security. These sustainable development impacts can be assessed using the [ICAT Sustainable Development Methodology](#). In addition, RE policies can drive the large-scale adoption of renewable technologies, attract private sector investment and substantially increase the share of renewables in a country's energy mix. The transformational impacts of such policies can be evaluated using the [ICAT Transformational Change Methodology](#).

Photo by Karsten Wuerth from Unsplash

A photograph of a wind farm in a field of tall grass at sunset. The sun is low on the horizon, creating a bright orange glow and long shadows. Several wind turbines are visible, silhouetted against the sky. The sky is filled with soft, orange-tinted clouds.

Part III: Assess the policy

Chapter 5:

Estimating renewable energy addition of the policy ex-ante

5.1 Overview of the steps to estimate renewable energy addition of the policy | 5.2 Estimate the technical potential of the policy | 5.3 Account for policy design characteristics that influence technical potential | 5.4 Incorporate financial feasibility factors affecting technical potential | 5.5 Account for other barriers affecting technical potential | 5.6 Summary of estimated renewable energy additions for policy examples

This chapter covers the first step in ex-ante GHG impact assessment – estimating the RE addition expected from the policy. “RE addition” refers to the incremental installation of RE capacity measured in megawatts (MW), increased electricity generation from renewable sources in megawatt hours (MWh), or energy storage capacity (MWh) attributable to the policy (e.g., via reduced curtailment). Several factors influence the expected RE addition, and these are examined in this chapter.



It is a key recommendation to:

- Estimate the technical potential for the assessment period of the policy.
- Identify policy design characteristics and account for their effect on the technical potential for the assessment period of the policy.
- Identify factors that affect the financial feasibility of RE technologies and account for their effect on the technical potential for the assessment period of the policy.
- Identify other barriers not addressed by the policy and account for their effect on the technical potential for the assessment period of the policy.

5.1. Overview of the steps to estimate renewable energy addition of the policy

This section describes a four-step approach to estimate the RE addition attributable to a policy. The approach is primarily intended for ex-ante assessments, where users estimate the expected impact of a policy that is being designed or planned. The same approach can also be applied for ex-post assessments to evaluate the performance of an existing policy. The four steps are as follows:

- **Step 1:** Estimate the technical potential of the policy
- **Step 2:** Account for policy design characteristics that influence technical potential
- **Step 3:** Incorporate financial feasibility factors affecting technical potential
- **Step 4:** Account for non-financial barriers affecting technical potential

Not all users need to apply all four steps. The choice of steps depends on the purpose of the assessment and the extent of analysis already undertaken at the policy or target-setting stage.

- Users assessing an existing policy against NDC targets or RE goals – where these targets are already defined in national policies – may omit step 1 (technical potential), as this analysis is often implicit in target-setting.
- In such cases, steps 2 and 3 may be integrated into step 4, where unfavourable

policy design features and financial feasibility factors are treated as barriers. The analysis can then focus on barriers that were not adequately considered during policy design.

- Some countries have already undertaken a comprehensive analysis of policy design, financial feasibility and barriers while developing their NDCs or RE targets. Where this is the case, steps 2–4 may be omitted. However, experience shows that such comprehensive analyses are not consistently carried out. For countries where this has not occurred, it is recommended to merge steps 2–4 and assess the remaining barriers affecting RE deployment.

The approach is also useful for policy course correction after an ex-post assessment, which has been done during the policy implementation phase. If ex-post assessments indicate that the policy has not achieved its intended objectives, it may require course correction. In such case, steps 2–4 should

be revisited in detail. This helps identify where adjustments in policy design, financial conditions or barrier removal may be needed.

Finally, the four-step approach can also be used by those who want to design a new policy (ex-ante). They should normally apply all four steps. The flow chart for applying these steps is given below in figure 5.1.

Figure 5.2. then shows these steps, which are described in detail in the following sections.

After completing the four-step process, users are encouraged to assess the plausibility of their RE addition estimates by benchmarking them against results from comparable countries.



Refer to [resources](#) such as REN21's [Global Status Reports](#) can support this comparison. If significant and unexplained discrepancies are observed, users should revisit and refine their assumptions, inputs and accuracy.

Figure 5.1. Flow chart – logic for applying the four-step approach

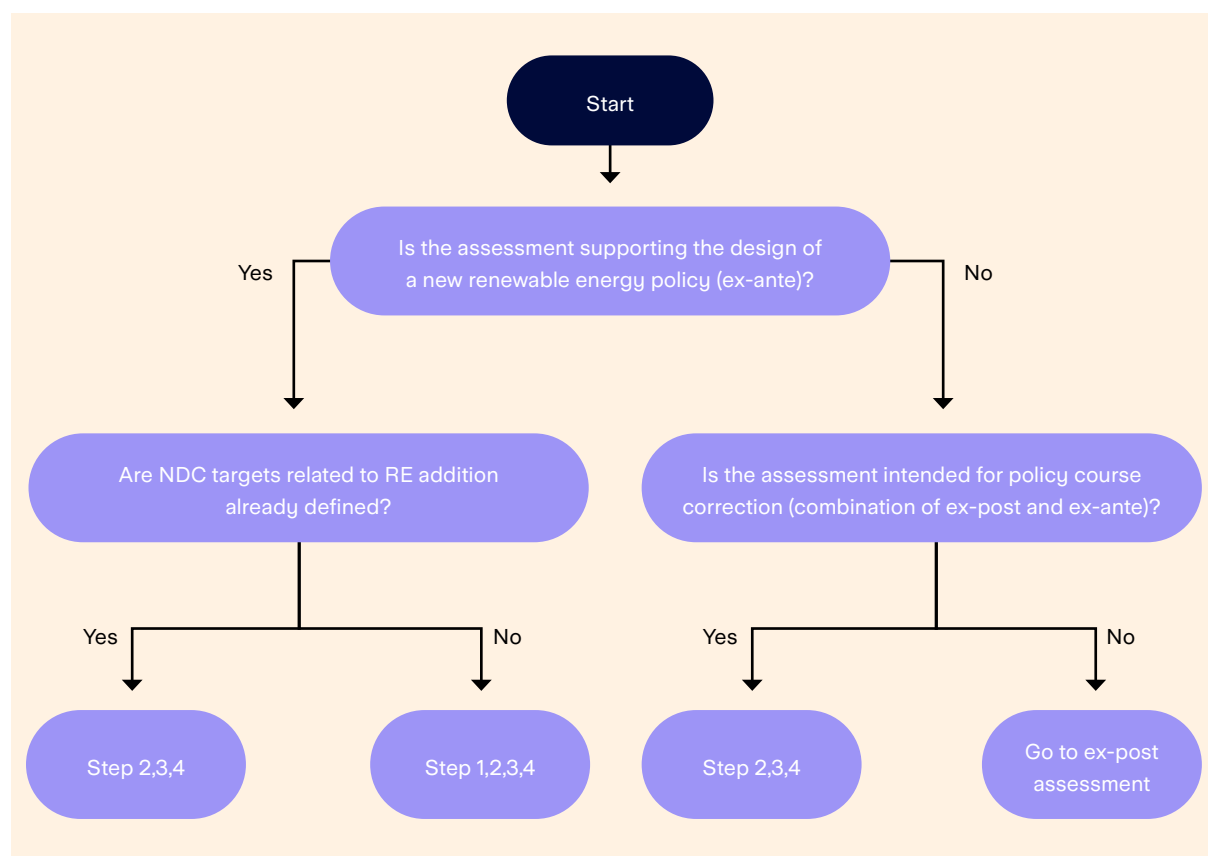
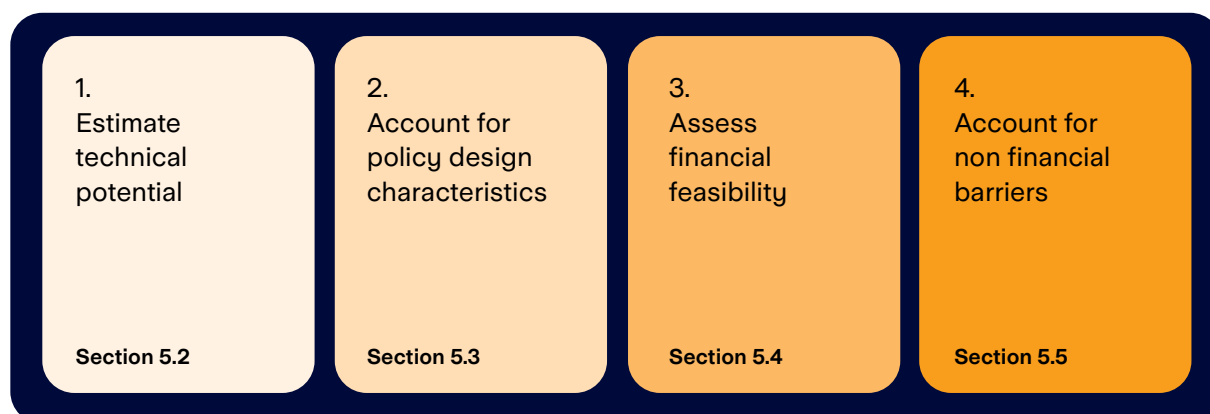


Figure 5.2. Steps for estimating RE addition of the policy ex-ante

Appendix C, table 5.C2 provides country-specific examples for each of the five types of policies. In addition, users are advised to consult peer country case studies that closely align with their national context and policy landscape.

5.2. Estimate the technical potential of the policy

This section describes how to estimate the technical potential for RE generation during a policy's assessment period. As defined in the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (Edenhofer et al., 2012), technical potential refers to the RE output achievable with full implementation of proven technologies, without considering economic costs or other barriers. Resource potential on the other hand, is the theoretical maximum energy potential of a resource – total solar radiation hitting a region, for example. Technical potential is thus the portion of the theoretical potential that can be utilized using current technology – accounting for efficiency of solar panels, for example.



Other types of “potential” are also defined in the literature; for reference, see [Appendix C, box 5.C1](#).

Figure 5.3 illustrates three examples of how policy caps on annual capacity limits may

determine the technical potential during the assessment period. A policy cap can refer either to a quantity-based cap – such as a maximum on additional installed capacity or electricity generation – or to a price-based threshold (e.g., one that determines support levels) used to set limits on policy costs (Fruhmann, 2015). In this context, the “policy cap” refers to the maximum RE installed capacity that the policy is intended to support.

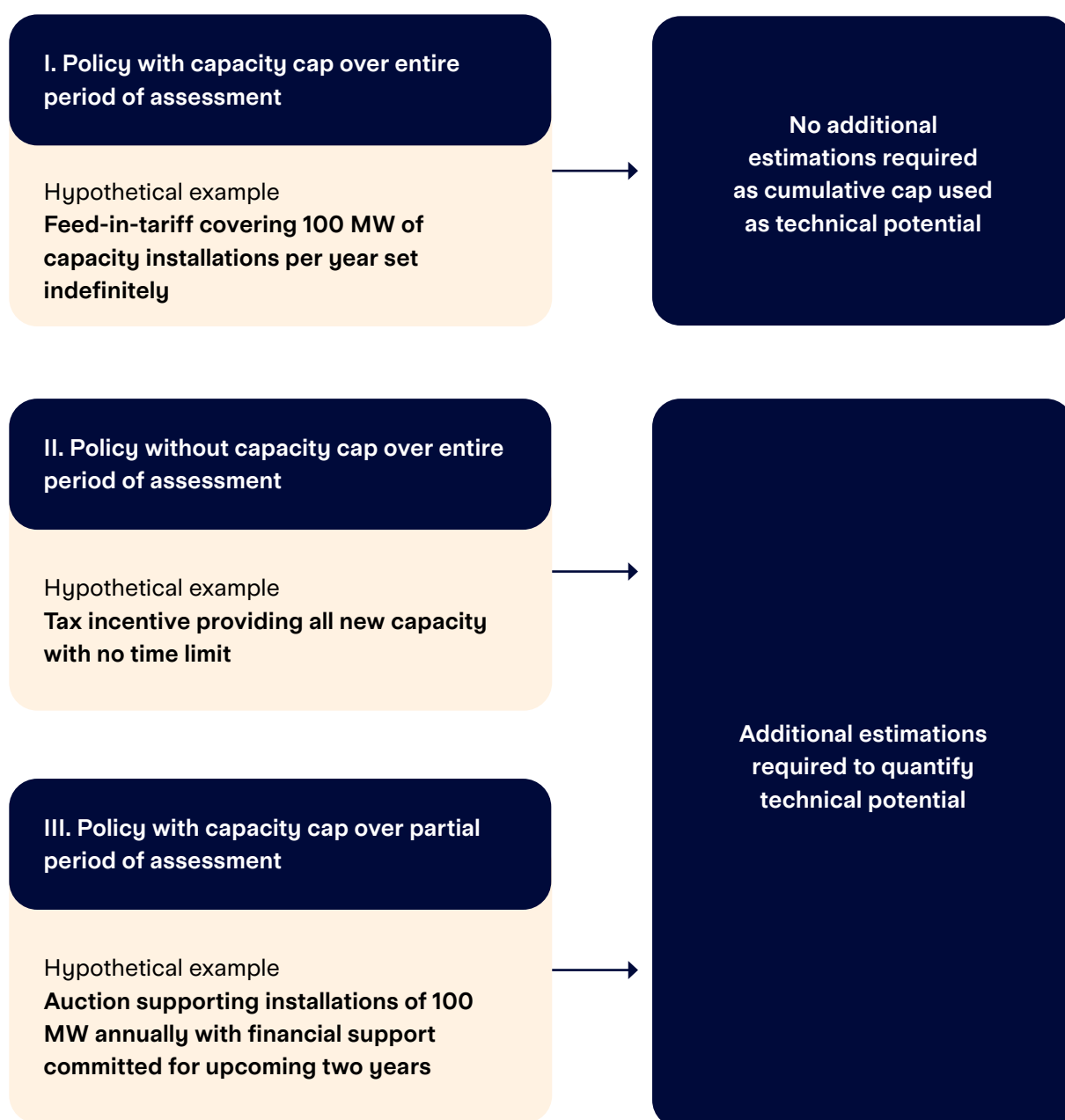
Depending on the policy, users may need to conduct additional analysis to identify the technically feasible potential for the assessment period.

The technical potential for the assessment period need not be quantified when a policy cap has been set for the entire assessment period (case I). Where such a policy cap does not exist or covers only part of the assessment period (cases II and III), the technical potential should be estimated using available information, such as scenario studies or databases on RE resource potentials.

5.2.1. Case I: Policy with capacity cap over entire period of assessment

For FiT policies, it is increasingly common to set a cap – either on the maximum amount of RE addition per year, or over the lifetime of the policy. In contrast, policy caps are typically implicit in the design of auctions and tenders, where a certain quantity is tendered, serving as a cap on the number of installations,

Figure 5.3. Three policy scenarios and their implications for estimating the technical potential for the assessment period



installed capacity (in MW) or electricity generated. Policy caps may be defined on a periodic, annual or even monthly basis.

As shown in figure 5.4, the aggregated periodic, annual or monthly policy caps form the starting point for estimating the RE capacity addition over the entire assessment period (e.g., 1,000 MW in this example). This approach assumes that the policy does not support any additional RE capacity beyond these caps.

However, users should reconsider using the aggregated policy caps as the basis for estimating RE additions in the following cases:

- **The policy cap is indicative and non-binding:** In this case, users should critically assess whether to use the aggregated non-binding cap as the estimate for RE additions. Alternatively, they may apply the approach described in section 5.2.2 to quantify technical potential for RE policies without a cap.

Figure 5.4. Case I – policy with capacity cap over entire period of assessment

Hypothetical example

Feed-in-tariff covering 100 MW of capacity installations per year set indefinitely

Year 1	Year 2	Year 3	Year 4	Year 5	Total over 10 years assessment period
100 MW	100 MW	100 MW	100 MW	100 MW	
Year 6	Year 7	Year 8	Year 9	Year 10	1000 MW
100 MW	100 MW	100 MW	100 MW	100 MW	

- **The policy cap is binding but subject to revision:** Even when the cap is binding, there may be potential for the policy to exceed its original targets if the Government revises the cap. In this scenario, the cap still serves as the starting point for estimating RE additions, but it may need to be adjusted if revised. For example, a Government might initially set a conservative cap due to limited experience with the technology or political resistance to further deployment. As technology penetration grows, acceptance and trust may increase, and the cap may be raised to reflect updated policy goals.

5.2.2. Case II: Policy without capacity cap over entire period of assessment

Where no policy cap is specified, the technical potential for the assessment period should be estimated using available studies or data on long-term technical potential for RE technologies. The long-term technical potential can be based on a study that estimates the deployment potential for a particular RE technology in a region or country during a specific time frame. Figure 5.5 shows an example of an RE policy without a cap over the period of assessment.

Based on data availability for the specific country or region, users may choose one of

the following two options to estimate the technical potential. Note that while available studies often report the resource potential, users should apply the approach in this section to derive the technical potential applicable to the assessment period. Preference should be given to the highest quality data or study available.

Option 1: Estimate the long-term technical potential from national or regional specific studies

Users can refer to studies by national experts or international organizations. It is recommended that users conduct a thorough literature review of national and international studies to allow an informed decision on which estimates to be made.

A variety of studies on the potential of RE in specific countries and regions are available. These studies often provide a scenario specifying a mix of possible technological options for a given country or region. [Appendix C, table 5.C3](#) presents a few examples of available studies and databases for national RE potentials. Some of these studies provide potential values for different future years. For specific countries, potentials can also be obtained from studies by national institutions. In Mexico, for example, the National Atlas of Zones with High Clean Energy Potential

Figure 5.5. Case II – policy without cap set for entire assessment period

Hypothetical example

Tax incentive supporting all new capacity with no time limit

Year 1	Year 2	Year 3	Year 4	Year 5	Total over 10 years assessment period
-	-	-	-	-	
Year 6	Year 7	Year 8	Year 9	Year 10	Estimation
-	-	-	-	-	

The dash is an abbreviation for not applicable

(Mexico, Ministry of Energy, 2023) contains information about geographical areas in Mexico with high RE potential (possible, probable and proven) per technology. IRENA has published the Global Atlas for Renewable Energy (Gherboudj and Jabesh, 2024), a web platform that allows its users to find maps of RE resources for locations across the world.

These studies and maps look at different types of RE potentials, including “technical potential” to “theoretical potential” and “economic potential”, as per the IPCC definitions (Edenhofer et al., 2012), and break them down into national or regional levels. Users should proceed with caution when referring to the “potential” values presented in these studies and know how to use them in the assessment.

Option 2: Estimate the long-term technical potential using existing technology-specific databases

Several international databases contain information on RE potentials for different RE technologies. The scope in terms of technology and country/region coverage varies from database to database. Whereas some databases are free of charge and publicly accessible, others are available at a cost.



Appendix C, table 5.C4 lists available international public and private databases that provide either RE potential for a region and technology, or specific parameters needed for calculating the maximum RE potential.

Appendix C, table 5.C5 provides examples of methodologies and tools that can be used to estimate the RE potential using input data available in databases listed in table 5.C4.

When estimating RE technical potential using the methods in table 5.C5, users should consider:

- Physical constraints: Natural limits like total sun hours or wind availability
- Energy content: The amount of energy in the resource, such as wind speed or solar radiation
- Theoretical physical potential: The maximum RE output based on these physical and energy characteristics

If national studies (the preferred option) or relevant international data are not available, users may collect local or national information from knowledgeable sources such as government ministries, academic institutions, consultants or by referencing data from

comparable countries in the region. As this approach can be time- and resource-intensive, expert input and review are strongly recommended throughout the process.



Expert judgement can support the estimation of long-term technical potential, drawing on technology databases and other relevant sources, as described in [Appendix C](#).

Deriving the technical potential for the assessment period from the long-term technical potential

RE potential studies and databases (options 1 and 2) often provide only long-term technical potential, which may not align with the policy's assessment period. In such cases, users should estimate the technical potential for the final year of the assessment period.

This can be done by interpolating the data between the current installed capacity (or generation) and the long-term technical potential, for each RE technology type. The results are then combined to calculate the total technical potential.

To carry out this estimation, users need to make assumptions about:

- The long-term target year by which the technical potential is expected to be fully achieved

- The expected deployment path – whether linear, S-shaped or another realistic growth trajectory

After estimating, users should check if the resulting annual growth rates (in installed capacity, electricity generation and share of generation) seem reasonable. These can be compared with historical growth rates, such as those found in IRENA's Global Trends database (IRENA, 2024b).

It is also important to factor in the time needed to build and connect RE plants. Since construction takes time, the estimates should reflect what is realistically achievable within the assessment period, assuming there are no external barriers (like those related to policy design characteristics, financing or others).

Cross-checking assumptions on growth and lead times ensures that the estimated technical potential is both robust and realistic for the policy context.

5.2.3 Case III: Policy with capacity cap over partial period of assessment

In some cases, the period over which a policy cap applies does not match the assessment period. Figure 5.6 shows an example where government financial support for a RE policy is limited to the first two years, while the GHG impacts are assessed over a 10-year period.

Figure 5.6. Case III – policy with capacity cap over partial period of assessment

Hypothetical example

Auctions supporting installation of 100 MW annually with financial support committed for upcoming two years

Year 1	Year 2	Year 3	Year 4	Year 5	Total over 10 years assessment period
100 MW	100 MW	-	-	-	
Year 6	Year 7	Year 8	Year 9	Year 10	200 MW *Estimation
-	-	-	-	-	

For the years covered by a specific capacity target or goal (capped years), the target itself may be used as a proxy for the technical potential, following the approach in section 5.2.1. For years in the assessment period that fall outside the target period (non-capped years), users may choose between a simplified approach – making informed assumptions based on capped-year data and policy trends – or a technical approach – estimating potential using the methodological options in section 5.2.2.

Regardless of the approach chosen, users should assess whether the duration of policy support affects RE deployment after the cap ends. In particular, early investment decisions may create infrastructure ‘lock-in’ that limits future expansion. For example, if unmet short-term electricity demand is addressed through new fossil fuel power plants, this can later constrain grid capacity, system flexibility or investment space for RE technologies.

If such lock-in effects are likely, the technical potential for the post-cap period should be adjusted downward to reflect these constraints. If no significant lock-in is expected, the technical potential may be assumed to evolve in line with the standard assumptions of the chosen approach. All such assumptions should be realistic, reflect country- and policy-specific conditions, and be clearly documented and justified.

5.2.4 Example of estimating technical potential for the assessment period

Before estimating the potential for a specific policy (e.g., an auction for solar or a FiT for biomass), users must first establish the overall physical and technical potential for that technology in the region. The following examples assume that this foundational assessment – identifying available resources and land constraints – has been completed.

This and the following chapters use an auction policy example to illustrate the assessment steps. Appendix C provides examples for other policies. To avoid duplication, the approach is not repeated for tax incentives, but the same logic applies to all five policies. See [Appendix C](#) for further details.

The following example illustrates how to estimate the increase in RE installed capacity (MW) attributable to an auction policy. It uses a step-by-step approach, with step 1 shown in box 5.1.

It should be noted that while policies like auctions or FiTs often pay for electricity generated (MWh), the physical impact of the policy is primarily realized through new capacity additions. For the purposes of this guide, these capacity estimates (MW) are the primary output of chapter 5, and will be converted into electricity generation (MWh) and final GHG impacts in chapter 6.

Box 5.1. Auctions (example 1) – Estimating technical potential for the assessment period for a tender policy with a partial policy cap

1. Estimate technical potential for the assessment period

The policy is designed to increase specific quantities of installed RE capacity over three consecutive years. The policy is administered by a public authority that set up three different rounds of tenders, one each year. Power producers will submit bids for these three tenders, and a number of winners will be selected to construct the total amount of installed capacity tendered for that year.

The following quantities of RE are scheduled to be tendered:

2020: 20 MW

2021: 60 MW

2022: 70 MW

The assessment period is 2020–2030. Because capacity additions are only specified for the first three years of the assessment period, the user follows the approach outlined under Case III: Policy with capacity cap over partial period of assessment (in section 5.2.3). The user refers to the total specified tendered capacities of 150 MW in 2020–2022 as a starting point, while making an informed additional assumption for 2023–2030.

The Ministry of Energy, which is responsible for the policy's design and implementation, emphasizes its intention to continue the policy after 2022. Ministerial staff indicate that the cap for 2022 was set based on a realistic assumption for the annual addition of RE capacity in the particular country context, once initial challenges were overcome. The user decides to assume that RE capacity is added at the rates reached by the policy in the third year (i.e., 70 MW per year for 2023–2030). Therefore, 640 MW is estimated to be the technical potential up to 2030.

640 MW

Similar examples of estimating technical potential for other policies, including for FiTs, net metering and VRE integration are provided in Appendix C, boxes 5.C2–5.C4. In addition, a detailed end-to-end example illustrating the full step-by-step methodology for implementing a hypothetical FiT policy can be found in Appendix E.

5.3. Account for policy design characteristics that influence technical potential

Step 2 involves accounting for the specific design characteristics of a policy that influence the realization of its technical potential. While applicable to various policy types, the concept of design characteristics primarily applies to procurement from third parties, such as through auctions, tenders or FiTs. These characteristics – including eligibility criteria, duration of support and capacity limits – act as the first ‘filter’ that determines how much of the physical resource identified in step 1 will likely be developed under the policy's rules.

Common design characteristics influencing RE policies include eligibility requirements, technology differentiation, payment structure, duration of financial support, and regulatory complexity. It is strongly recommended to identify these characteristics and account for their effects on the technical potential.

Table 5.1 lists key design characteristics for auction policies and describes their influence on technical potential. **Appendix C, tables 5.C6–5.C10 provide similar information for FiTs, tax incentives, net metering and VRE-grid-battery storage policies.**

Users should use these tables to:

- Identify relevant design characteristics for their country context (and business model in case of VRE integration)
- Describe how these characteristics affect RE deployment (to the grid-scale batteries in case of VRE integration)
- Estimate their overall impact on RE (on grid-batteries in case of VRE integration) technical potential during the assessment period

Note on VRE integration policy with grid-battery storage

It is important to distinguish between VRE integration policies – which focus on facilitating the dispatch of renewable electricity from existing or planned RE plants – and other policies aimed at promoting renewable electricity production.

In the case of VRE integration, a variety of business models exist for establishing grid-battery storage, including utility-owned models, IPP-owned models, hybrid models (co-located battery and RE), PPPs and ESaaS – particularly relevant in developing countries.

Table 5.1. Auction policies – influence of policy design characteristics on the technical potential

Design characteristic	Description	Influence on technical potential
Auction demand and design	Quantity of energy auctioned and technology/project-specific design	Determines how much capacity can be added; poor design can reduce effectiveness.
PPA longevity	Duration and stability of PPAs	Longer, stable contracts lower financing risks and increase the chance of meeting the potential.
Qualification requirements	Criteria bidders must meet (e.g., reputation, grid access, site readiness)	Lack of clear or overly strict criteria may limit bidder participation and increase risks, reducing the technical potential.
Bidding procedure	Type of auction, level of competition and how winners are selected	Poor procedures can lead to underbidding and contract failures, slowing RE growth.
Seller liability requirements	Penalties, timelines and risk-sharing in contracts	Too strict or loose requirements can either discourage bidders or lead to poor project delivery, affecting RE outcomes.

Sources: Adapted from Lucas, Ferroukhi and Hawila (2013); Ragwitz et al. (2014); Ferroukhi et al. (2015).

The concept of design characteristics primarily applies to procurement from third parties – defined here as IPPs, which are external to the primary relationship between the regulator and the utility. In a utility-owned model (including investor-owned utilities), certain procurement design characteristics may have a more limited or indirect impact on deployment because the storage system is owned directly by the utility. However, policy design remains relevant as it dictates the technical performance standards, eligibility and timelines that the utility must follow, many of which are ultimately defined in the request for proposals (RFP).

Additionally, battery storage systems often serve multiple functions beyond VRE integration, and can provide up to 13 services (Fitzgerald et al., 2015), leading to a stack of multiple revenue streams. Technical and operational requirements in the RFP may reflect these roles, which include ancillary services (e.g., frequency regulation and voltage support), peak shaving, transmission and

distribution deferral (where battery storage, along with other alternatives such as demand response and distributed generation, can help postpone or avoid costly upgrades), and black start capabilities (which enable power plants to restart and energize the grid independently without external power during a blackout). Because these requirements significantly impact the financial feasibility and technical design of the system, users should consult supplemental technical guidance. Recommended resources include the Asian Development Bank's Handbook on Battery Energy Storage System (Kim et al. 2018) and IRENA's Innovation Landscape for a Renewable-powered Future: Solutions to integrate variable renewables (Anisie et al., 2019). Users interested in advanced developments in this area can refer to publications from the National Renewable Energy Laboratory (NREL – now the National Laboratory of the Rockies, NLR) (Cole and Karmakar, 2023) and IEA (Petropoulos et al., 2024).

Estimating the overall influence of policy design characteristics

To estimate the overall impact of each policy design characteristic on the RE technical potential during the assessment period, users can follow these steps:

1. **Make a first-order estimate** of how each design characteristic might influence expected RE addition. This can be expressed either as a fixed capacity deduction (e.g., 200 MW) or as a percentage reduction (e.g., 5 per cent) applied to the technical potential. Estimates should be informed by prior experience (domestic or international) or relevant literature.
2. **Consult with stakeholders and experts** (e.g., power systems, electricity policy or grid specialists) to validate and, if necessary, revise the first-order estimates. Where there is high uncertainty or diverging

opinions, users may apply an uncertainty range (e.g., 150–200 MW or 5–10 per cent).

3. **Adjust the technical potential** by deducting the validated estimates to account for the impact of policy design characteristics.



Consultations with stakeholders and technical experts can help validate estimates of the influence of policy design characteristics on the technical potential.



5.3.1. Example to account for policy design characteristics

In the event of an auction, impact of policy design characteristics on renewable addition is illustrated in box 5.2.

Similar examples for FiTs, net metering and VRE grid-battery storage policies are given in [Appendix C, boxes 5.C5–5.C7](#). In addition, the end-to-end example in [Appendix E](#) illustrates how this step is applied in practice for FiTs.

Box 5.2. Auctions (example 1) – Using policy design characteristics to refine expected RE addition of the policy for the assessment period

1. Estimate technical potential for the assessment period

2. Account for policy design characteristics

The design characteristics for the auction policy are as follows:

Auction demand/auction design – technology-specific stand-alone auctions

- 2020 – 10 MW of solar, 10 MW of wind
- 2021 – 30 MW of solar, 20 MW of wind, 10 MW of biomass
- 2022 – 30 MW of solar, 30 MW of wind, 10 MW of biomass
- 2023–2030 – 30 MW of solar, 30 MW of wind, 10 MW of biomass (all annually)

Longevity of the PPA – Duration of tariff is 25 years for solar, 20 years for wind and 20 years for biomass.

Qualification requirements – Pre-qualification phase with requirements to display experience, as well as financial and technical capacity to implement projects.

Winner selection process – One-round winner selection based on price and quota of energy (with no ceiling price), with several bidders selected.

Sellers' liabilities requirements – Penalties for delay and underperformance determined in PPA, guarantee paid at signature of PPA, termination of PPA as last resort.

Because of a lack of specific quantification methods, a qualitative approach is used to estimate the influence of each policy design characteristic (above) on the technical potential for the assessment period that can be realized by the policy. To start, the user made first-order estimates of how each policy design characteristic might influence the technical potential for the assessment period. These estimates were discussed in a consultation workshop with national energy sector experts. The conclusions suggest that the policy design characteristics that are likely to affect the technical potential for the assessment period are as follows:

1. **The predefined qualification requirements** are likely to directly reduce the technical potential for the assessment period. The consultation revealed that only a small number of companies have sufficient financial and technical capacity to implement projects. These qualification requirements were introduced to ensure the successful implementation of the auctioned capacity. However, since the industry needs a few years to develop further expertise, the expected RE addition of the policy for the assessment period analysed is reduced by 60 MW, from 640 MW (the technical potential for the assessment period determined in the previous step) to 580 MW.
2. **The sellers' liability requirements** are likely to reduce the expected RE addition of the policy for the assessment period, because a number of potential power producers cannot provide the required guarantee at the signature of the PPA. These liability requirements were introduced to ensure the successful implementation of the auctioned capacity. After consultation with the two industry experts and a review of the current project pipeline in the country, it is estimated that this reduces the maximum achievable impact by a further 30 MW, from 580 MW to 550 MW.
3. After analysing whether the specifications of the longevity of the PPA might reduce the expected RE addition of the policy, no further downward adjustments have been made, because the duration has been set after consultation with power producers to ensure a sufficiently long PPA duration.

After accounting for all policy design characteristics, the expected RE addition of the policy for the assessment period is expected to be 550 MW (compared with 640 MW originally).

550 MW

5.4. Incorporate financial feasibility factors affecting technical potential

This section describes the steps to develop an initial estimate of the policy's impact on the financial feasibility of RE technologies. It also provides guidance on accounting for alternative cost factors, the influence of other policies within the sector and existing sector trends. Financial factors that may affect grid-battery storage are covered in section 5.4.3.

Financial feasibility comparing generation cost of electricity and its selling prices, which has several variations. Therefore, it is essential to establish a common language for the market structures and price benchmarks used throughout this assessment (see box 5.3).

RE policies can provide financial incentives that directly influence the financial feasibility of RE technologies and, consequently, the expected RE addition during the policy's assessment period.

In this step, users estimate the policy's impact on the financial feasibility of RE technologies, then factor in alternative cost considerations,

other sector policies and market trends. Other financial barriers are covered in the barrier analysis.



It is a key recommendation to identify factors affecting the financial feasibility of RE technologies and incorporate their impact on the technical potential for the assessment period. Existing cost-benefit analyses (e.g., from the policy design phase) should serve as foundation and be updated as needed.

5.4.1. Identify factors that affect the financial feasibility of renewable energy technologies

Users should determine how much financial support a policy provides and how this affects the viability of RE technologies. Whenever possible, they should use and update existing cost-benefit analyses to reflect current conditions.

Box 5.3. Energy market structures and price concepts

To evaluate financial feasibility, users must first identify the market context in which the RE policy operates. The relevant price to use in calculations depends on the market structure:

- **LCOE:** Average net present cost of electricity generation for a generator over its lifetime. This is the price a generator must receive to break even over its lifetime.
- **Wholesale market price:** The price at which electricity is traded in competitive markets. Relevant for utility-scale projects selling directly to the grid.
- **Retail electricity tariff:** The price paid by end-users. This is the benchmark for behind-the-meter projects (e.g., rooftop solar), where the 'revenue' is the avoided cost of buying from the utility.
- **FiT:** A fixed, policy-guaranteed price per unit of energy. In auctions, this is the price resulting from a competitive bid.
- **Avoided cost:** The expenses a utility or consumer saves by using RE instead of the next cheapest alternative (often marginal fossil fuel generation).

Several key factors influence financial feasibility:

1. RE-specific factors

- **Technology costs:** Including capital, operation and maintenance, and fuel (e.g., biomass). Local costs may be higher due to limited expertise or early market development, but can decrease over time with experience and innovation.
- **Technical characteristics:** Including the capacity, load performance and operational lifetime of the technology in the local context.
- **Project financing:** Depending on sources such as equity, private debt or public loans. Financing terms (interest rates, loan duration) are reflected in the WACC.
- **Expected returns:** Measured by the internal rate of return (IRR), which represents the project's average annual return, where net present value (NPV) is zero.



Refer to this guide's [assessment toolkit](#) for additional resources on estimating the financial factors such as WACC.

2. Electricity market factors

- **Costs of alternative technologies:** Such as fossil fuel or nuclear, including their capital, operational and fuel costs.
- **Electricity prices:** Determined by wholesale market conditions or private contracts, and influenced by time and market structure.
- **RE resource availability:** Varies by location (e.g., wind strength), affecting energy production and economic viability.

Together, these factors shape how financially feasible RE technologies are in a specific country or region.

To assess feasibility, users can rely on the following sources (in order of priority):

- Estimates developed during policy design
- National cost studies (e.g., from low-emission development strategies)

- Global databases with national-level data (e.g., IRENA RE cost data)

5.4.2. Evaluate financial feasibility of renewable energy technologies

It is important to be able to evaluate the financial feasibility of specific RE technologies. To do so, users can follow the steps below.

Step 1: Calculate the levelized cost of electricity for different renewable energy technologies

The first step in evaluating the financial feasibility of RE technologies is to calculate the LCOE, a commonly used metric for comparing electricity generating costs across different technologies. Because the LCOE is the unique cost of an energy project, representing the present value of the costs over the lifetime of the project, it can be used to compare the cost competitiveness of different technologies for the same location. As a result, the LCOE is often taken as a proxy for the average electricity price that a project must receive in a market to break even over its lifetime.



[Appendix 5.C1](#) provides further information on how to calculate the LCOE. Users can also refer to publicly available LCOE quantification tools such as the Excel spreadsheet tool provided by Agora Energiewende (Fürstenwerth, 2015), the [Greenhouse gas Abatement Cost Model \(GACMO\)](#) tool of the UNEP Copenhagen Climate Centre (UNEP-CCC, 2025), or development tools tailored to country-specific circumstances.

In some country contexts, users can use more sophisticated LCOE tools – for example, to assess financial derisking policy options, using the [Derisking Renewable Energy Investment \(DREI\)](#) methodology of the United Nations Development Programme (UNDP).

Other methods used by public and private investors and policymakers can also be used in this context. However, commonly used LCOE calculation tools do not by themselves capture all project finance or market risk factors.

The financial attractiveness of technologies can be assessed by comparing the LCOE with the relevant support level, such as feed-in tariff or auction price, or with the cost of the generation it may displace under incentive-based policies. For the latter comparison, these can be:

- The LCOE for existing plants, if it is clear which fossil fuel plants will be displaced as a result of the policy
- The average electricity generation costs across the electricity grid
- The LCOE for power plants that would have been built in the absence of the policy

The LCOE should be calculated separately for each RE technology. Since the LCOE of RE power plants might vary widely, depending on geographical conditions such as the wind and solar resource, a location differentiation should also be considered. For example, users might conduct separate calculations for solar PV installations in different regions of the country if the solar potential can be divided into different geographic areas. The proximity of a prospective RE installation site to energy demand centres may also be an important cost consideration because it affects the costs of transmission, which can be significant for long distances.

Project financiers may compare the discount rate used in the LCOE calculation, often based on WACC, with the project's IRR to assess if the project is value-creating. In general, a project is expected to be acceptable if its IRR is as high as WACC, since this implies a non-negative NPV. Companies often set a minimum acceptable IRR before investing.



Refer to this guide's [assessment toolkit](#) for additional resources on calculating financial parameters such as LCOE and WACC.

Step 2: Compare the LCOE with total expected revenue (market price and policy incentives)

The second step involves evaluating the attractiveness of a given technology by

comparing its LCOE against the total expected revenue it generates. Feasibility is achieved when the total revenue per unit of electricity meets or exceeds the LCOE, providing a clear 'break even' point for potential investors.

In many policy environments, total revenue is the sum of electricity sales revenue and any additional policy support or financial incentives (subsidies, premiums or other). To ensure a technically sound 'apples to apples' comparison, users should apply one of the following two calculation approaches based on the policy type:

1. **Approach A: Net LCOE (investment-based support):** For incentives that reduce upfront costs (e.g., capital grants, ITCs), users should deduct the incentive value from the capital expenditure (CAPEX) before calculating the LCOE. This 'net LCOE' is then compared directly against the market price or policy tariff to assess economic competitiveness.
2. **Approach B: Total revenue (production-based support):** For incentives that reward generation (e.g., feed-in premiums, green certificates), users should add the incentive value to the expected electricity sales revenue. This 'total revenue' is then compared against the standard LCOE.

Applying the comparison across policy scenarios

To simplify the assessment, users can categorize their specific policy into one of the following scenarios:

1. **Guaranteed price scenarios (FiT/auctions):** These typically provide a fixed, guaranteed price for all electricity produced. No addition or deduction is required; the LCOE is simply compared directly against the awarded policy price. The project is economically viable if $LCOE \leq \text{policy price}$.
2. **Top-up scenarios (premiums/certificates):** These provide a 'top-up' on top of the market price. Use approach B. The project is economically viable if $LCOE \leq (\text{market price} + \text{incentive value})$.

3. **Cost-reduction scenarios (grants/tax credits):** These reduce the cost of building the project. Use approach A. The project is economically viable if $\text{net LCOE} \leq \text{market price}$.

Critical considerations for comparison

Users should use caution when making comparisons between calculated LCOE and FiT or PPA prices. These require additional considerations – for example, the duration of the payment introduced by a respective policy, compared with the economic life of assets. The IRENA report Renewable Power Generation Costs in 2017 presents two examples of how such factors can affect results when comparing the LCOE with an electricity tariff (Ilas et al., 2018, box 1). In general, users should always aim to consult with national or international experts to discuss the methodological approach chosen and the underlying assumptions.



Expert judgement can support the selection of the appropriate methodological approach and the use of suitable assumptions when evaluating financial feasibility.

Furthermore, for VRE technologies, LCOE is a useful cost benchmark, but does not capture the time-dependent market value of electricity or system integration costs. Where data is available, costs can be compared against time-weighted wholesale prices, but it increases complexity. The IEA has developed value-adjusted LCOE (VALCOE) (IEA, 2025a; IEA, 2025b), which modifies the standard LCOE to include the energy, capacity and flexibility value a technology provides to the system, offering a more complete metric of competitiveness for variable renewables compared to dispatchable power³.

Accounting for tax incentives

Users evaluating tax incentive policies can account for financial implications by incorporating tax effects into project cash

flows. These include the impact of income taxes, the present value of the depreciation tax shield, ITCs, the effective corporate income tax rate, the allowable tax depreciation rate over time, and the capitalization discount for depreciation purposes.

Such adjusted LCOE calculations can further account for the fact that the assumed useful life of an investment for tax purposes is usually shorter than the economic life. In the case of a PTC, for example, a dollar-for-dollar subsidy in terms of a fixed premium per kilowatt-hour of produced electricity is added separately to the LCOE calculation while also accounting for the tax credit's lifetime.

Detailed explanation of how to include both ITCs and PTCs can be found in Levelized Cost of Electricity Calculator: A user guide from the Stanford Graduate School of Business (Comello, Glenk and Reichelstein, 2017). Alternatively, the publication Effects of Incentives for Renewable Energy in Colombia by Pontificia Universidad Javeriana (2016) provides detailed guidance on how to incorporate tax deductions and accelerated depreciation into LCOE calculations (Villada Duque, López Lezama and Muñoz Galeano, 2017).

Global weighted LCOE of power generation from various RE sources has been coming down – users interested in LCOE trends can refer to Dardour, Ayres and Zamora (2025).

Step 3: Account for other cost considerations in a national context (if relevant)

As discussed in the previous steps, the electricity generated by RE technologies will usually be fed directly into the grid. Therefore, the LCOE is compared with the electricity market wholesale price to identify the financial feasibility of such technology in a competitive market setting, or the financial incentive provided by an RE policy.

In some country contexts, however, alternative cost considerations need to be accounted

3. Methodological note: The IEA introduced VALCOE specifically to address the 'LCOE gap' for VRE technologies. Detailed methodology for it is in their Global Energy and Climate Model: Documentation – 2025 (IEA 2025a). Using the methodology requires high modelling skills. For practical reasons, users without these skills can stick to LCOE.

for when analysing the financial feasibility of certain RE technologies from the perspective of the investor. This crucially depends on the country context and the policy design characteristics and market risk factors.

For example, if a tax incentive policy is eligible regardless of whether the electricity is fed into the grid or consumed by the investor directly (without ever being fed into the grid), households or industrial entities (as the investors in solar PV installations) might install additional RE capacity, even if the LCOE is above the electricity wholesale market price. This is because the investors (i.e., households and/or industrial entities) compare the location-specific electricity production costs, plus the granted financial support, with the prices they pay as end consumers of electricity from the grid.

Retail electricity prices are typically higher than wholesale market prices because they reflect not only the cost of electricity generation, but also of transmission and distribution network charges, system operation costs, and policy-related components such as taxes, levies and support schemes.

In such cases, users should replace what is referred to as wholesale market price in step 2 with the cost of the alternative (i.e., the end-consumer price):

- **Residential customer's own consumption** (ideally with net metering in place) – comparison of production costs plus financial support with end-consumer prices.
- **Industrial generation for own consumption**
 - Separate analysis should be done for all RE technologies considered.
 - Calculations provide users with an indication of whether there will be any capacity extension; if so, analysis will indicate the specific technologies (and possibly areas) where this applies.
 - End-consumer prices for industrial entities should be compared with RE production prices (with and without FiT or tax incentive).

- The feasibility of the analysis depends on regulations in the jurisdiction (e.g., whether 'off-site' generation is allowed and, if so, whether policies on transmission exist).

If industrial entities and/or households install RE capacity for their own consumption under a given policy (under which financial support is granted regardless of whether the electricity is fed into the grid), this might result in higher overall capacity for RE deployment than would be generated by comparing LCOEs with wholesale market prices. Again, users might need to account for regional differences and conduct separate analyses for different regions.

Users should consider whether such additional analysis is necessary given the country context and policy design characteristics of the respective policy.

Step 4: Consider the effect of other policies in the sector (if relevant)

Other policies in the sector may affect the economic attractiveness of RE technologies. They may also enable or impede the implementation of the policy, and may continue into the future or be discontinued. Policies that may interact with the economic attractiveness of RE technologies include:

- Emissions trading programmes, which through GHG emissions pricing may provide an additional incentive for RE technologies by increasing the cost of alternative technologies
- Taxes, such as energy or carbon taxes
- Energy regulations, such as efficiency standards and mandatory closing of inefficient plants, and quotas for fuels
- Subsidies, such as fossil fuel subsidies, or direct and indirect electricity subsidies
- Sustainable public procurement requirements

The guidance provided in section 4.4.2 may also be helpful in determining the effects of other policies.

Step 5: Consider the effect of sectoral trends (if relevant)

Sectoral trends can reinforce or counteract RE policies and the economic attractiveness of RE technologies; they may affect electricity tariffs or wholesale market prices. Sectoral trends to be considered include:

- Changes in fossil fuel prices that can cause shifts between fossil fuels (e.g., shift from coal to natural gas due to lower costs of natural gas) or alter the financial feasibility of RE power plants
- Public support or opposition to certain technologies, such as offshore wind turbines
- Global trends in technology costs, whether these relate to RE technologies (e.g., falling costs of solar PV panels) or fossil fuel-based plants, including carbon capture and storage
- Shifts in consumer behaviour, such as increasing demand for renewable electricity

To identify relevant trends, users can refer to sectoral studies on national or global developments in the sector. They can also consult with national experts and relevant stakeholders from universities, ministries, the private sector or the public. For example, users could refer to recent studies on global and local price development for fossil fuels to evaluate whether the projected trends significantly affect the overall costs of RE technologies in comparison with traditional fossil fuel technologies (e.g., cost reductions of natural gas due to accelerated fracking exploration).



Consultations with stakeholders and expert judgement can help identify effect of sectoral trends on technical potential of renewable energy.

The existence and impact of sectoral trends are highly dependent on national sectoral circumstances. Careful evaluation is needed of how, and to what extent, such trends affect the economics of renewables.

5.4.3. Financial factors that may affect the financial feasibility of grid-battery storage

Key financial factors influencing the financial feasibility of grid-scale battery storage include the following:

- **Upfront capital cost/CAPEX:** This has a major impact on financial feasibility. In utility-owned models, high CAPEX can directly affect internal budget allocations, potentially delaying or limiting deployment.
- **Financing terms:** These include loan interest rates, tenor and repayment structure. Concessional financing (e.g., from development banks) can significantly improve project viability.
- **Government incentives (grants/subsidies):** Financial support from the Government can reduce net capital or operating costs, making projects more financially feasible.
- **Depreciation and ancillary revenue:** Accelerated depreciation helps recover costs more quickly. Where permitted, revenues from ancillary services (e.g., frequency response) can improve returns and offset investment.
- **Utility-owned model – specific factors:**
 - Regulated return on equity (RoE): Regulatory limits on RoE can affect the investment attractiveness of battery projects.
 - Tariff recovery mechanism: Determines whether and how battery costs can be recovered through consumer tariffs.
- **IPP and other private models – specific factors:**
 - Revenue risk and creditworthiness of off-taker: The utility's payment reliability impacts financing and investment risk.
- **PPA design and tenure:** Long-term, clearly defined PPAs improve revenue certainty and bankability of storage projects.
- **Levelized cost of storage (LCOS):** To be used along with LCOE for integrated

projects. Essential to account for the specific per-unit cost of discharging stored energy, which LCOE alone does not capture.⁴

- **Revenue stacking potential:** This refers to the ability to earn money from several different sources at the same time to increase total profit. These include ancillary services (e.g., quickly balancing grid, frequency stabilization), capacity markets (as a standby support to provide power when grid is stressed) and price arbitrage (buying electricity when cheap and selling when price is high). It is necessary because storage projects often require multiple income streams to become financially viable.
- **Degradation costs:** Every time a battery charges and discharges, its total storage

capacity shrinks slightly; these costs represent the loss in the battery's value over time. Taking degradation costs into account is crucial to reflect how a battery's physical wear-and-tear over time reduces its capacity, and negatively impacts the project's long-term return on investment.

5.4.4. Examples of using financial factors to refine the technical potential for the assessment period

The example in Box 5.4 below illustrates how to refine expected renewable energy addition based on financial factors attributable to an auction policy. Similar examples for FiTs, net metering and VRE grid-battery storage policies are given in [Appendix C, boxes 5.C8–5.C10](#).

Box 5.4. Auctions (example 1) – Using financial factors to refine expected RE addition of the policy for the assessment period

1. Estimate technical potential for the assessment period

2. Account for policy design characteristics

3. Account for effect on financial feasibility of RE technologies

Since the auction policy provides separate auctions by technology and there is no ceiling price for the auction, the financial feasibility assessment does not result in a downward revision of the technical potential for the assessment period. However, access to financing in the country is very limited, and only a small number of private investors are willing to invest in RE. This limits the number of plants that can be constructed.

A consultation with two national experts on project finance in the electricity generation sector provides further insights. A comparison of the estimated investment finance needed for all tendered electricity capacity with the estimated financing available for private entities shows that the overall achievable RE addition with the existing financing is 400–500 MW. To be conservative, and given the high uncertainty, the expected RE addition of the policy for the assessment period, after accounting for financial feasibility, is refined to 450 MW.

450 MW

4. Integrated projects refer to power plants that combine renewable energy generation (like solar panels or wind turbines) with battery storage at the same location. Instead of being two separate businesses, they function as a single unit: the solar/wind components generate the electricity, and the integrated battery 'smooths out' the supply by storing power when the sun is shining and releasing it when it is needed most. Integrated projects are applicable to various battery-storage business models.

5.5. Account for other barriers affecting technical potential

Several barriers can hinder RE deployment, including technical, regulatory, institutional, market, financial, infrastructure, awareness and public acceptance barriers. Such barriers also indirectly reflect risks for investors, financiers or other actors to develop and implement RE projects in a given country context. It is a key recommendation to identify other barriers not addressed by the policy, and account for their effect on the technical potential for the assessment period of the policy. The barrier analysis focuses only on those barriers not directly addressed by the policy being assessed. Accounting for barriers methodology is the same for deployment

of grid-battery storage for VRE integration, though some barriers may be different within the barrier categories.

Users should follow the steps below to identify barriers and account for their effect on the technical potential for the assessment period of the policy.

5.5.1. Step 1: Identify barriers

Table 5.2 lists barrier categories and provides descriptions and examples for each. This categorization can be used to identify and describe barriers to RE deployment in the geographic area of the policy, and to note if no barriers are identified for a given barrier category.

Table 5.2. Barrier categories

Barrier category	Description	Examples
Technical	- Technical standards (e.g., uniform engineering or technical criteria, methods, processes and practices) lacking for some RE technologies. - Lack of sufficient technology providers. - Insufficient transmission and distribution infrastructure to connect new RE capacity to the grid, especially where RE resource potential is highest. - Grid integration complexity (grid-battery storage case).	- No technical standard exists for a biomass technology that is eligible under the policy. - There is a limited number of technology providers for a certain technology that are eligible under the policy. - Outdated transmission and distribution infrastructure prevents grid connection of newly installed capacity (e.g., no transmission lines exist to connect wind generation in remote areas). - Inadequate supervisory control and data acquisition (SCADA)/energy management system (EMS) makes real-time control and dispatch difficult.
Regulatory and policy uncertainty ⁵	The risk that the broader country-level regulatory and policy framework might change or be inconsistently applied, impacting the implementation environment. This refers to external risks rather than the specific design features of the RE policy itself.	Lack of an independent energy regulator; retroactive changes to general laws; uncoordinated permitting processes across government levels; or political instability.

5. Users should distinguish between the general regulatory environment (step 3) and the specific design characteristics of the RE policy (step 2) to avoid double-counting risks in the financial assessment.

Barrier category	Description	Examples
Institutional and administrative	- Lack of strong and dedicated institutions to carry out policies. - Permits for new RE plants are difficult to obtain, approval procedures are lengthy and cumbersome, or there is a lack of spatial planning for RE. - Unclear procedures and responsibilities, and/or complex interactions and lack of coordination between the various authorities involved. - Other barriers in the energy system, such as existing industry, infrastructure and energy market regulation; intellectual property rights; tariffs on international trade; and allocation of government financial support. - Limited utility capacity (grid-battery storage case).	- Several institutions claim responsibility for implementation of the policy. - Procedures on how to participate in, or receive assistance from, the policy are unclear, discouraging market actors. - Utilities lack internal skills and dedicated teams to plan and operate storage.
Market	- Inconsistent pricing structures that put renewables at a disadvantage. - Asymmetrical information between market actors. - Market power and subsidies for fossil fuels. - Blockage of incumbent actors and limited access of new actors to the market. - Import tariffs and technical barriers that impede trade in RE technologies and equipment. - Access to market. - No capacity, energy and frequency regulation markets (grid-battery storage case).	- Existing fossil fuel subsidies (direct or indirect) prevent large-scale RE deployment through the policy. - Incumbent market actors have an information advantage, and direct or indirect influence on policy design process, limiting access for new market actors. - High import tariffs or domestic content requirements hinder deployment of technologies - Lack of market signals reduces private investment interest.
Financial or budgetary ⁶	- Financial constraints, including public budget limitations not already considered in step 3 (financial feasibility). - Concerns about possible devaluation of asset value. - Disproportionately high transaction costs in relative terms. - Total budget available for policy measures (e.g., for tax incentives, FiTs).	- A lack of budget for policy implementation or administration. - High transaction costs, including legal, permits, due diligence costs, etc. - Substantial concerns about financial solvency of state-owned utilities discourage market actors from using the policy. - Institutional credit constraints.

6. To avoid double-counting, users should only include financial barriers here that are not already reflected in the parameters used for the financial feasibility assessment in step 3 (e.g., adjustments to the WACC, discount rate, specific technology costs, etc.).

Barrier category	Description	Examples
Infrastructure	▪ Lack of flexibility of the energy system (i.e., of the electricity grid to integrate or absorb RE). ▪ Energy markets are not prepared for RE (e.g., integration of intermittent energy sources, grid connection and access are not fairly provided). ▪ Higher grid connection costs for RE. ▪ Weak or outdated grid infrastructure (grid-battery storage case).	▪ History of technical problems with grid infrastructure prevents decentralized access of RE to the grid. ▪ Existing grid may not support fast response or two-way power flow. ▪ Lack of advanced forecasting systems which prevents the grid operator from accepting higher VRE increments, despite physical capacity availability.
Lack of awareness of RE and skilled personnel	Insufficient knowledge about availability, benefits and performance of RE. ▪ Insufficient numbers of skilled workers, and lack of training and education. ▪ Lack of general information and access to data relevant to RE deployment (e.g., deficient data about natural resources). ▪ Lack of experience and expertise among the relevant stakeholders, including project sponsors and power producers, investors and financiers, and regulators and authorities. ▪ Limited technical know-how (grid-battery storage case).	▪ Insufficient skilled workers are available for installation of wind turbines. ▪ Few trained professionals in battery technology and system integration.
Public acceptance and environmental concerns	▪ Linked to experience with planning regulations and public acceptance of RE. ▪ Lack of research into the more complex interactions between RE technologies and the environment. ▪ Competition with other interests in the geographic area (e.g., fishing, shipping and aviation, recreational use of land, archaeological and historical heritage interests, civil and military airport interests). ▪ Concerns over battery safety and disposal (grid-battery storage case).	▪ Public acceptance of the policy is low because of perceived high economic and social costs, and a lack of understanding and misleading information. ▪ Environmental concerns exist as a result of major investments in new infrastructure, particularly overland transmission lines. ▪ Communities fear fire risk and improper waste handling.

5.5.2. Step 2: Prioritize barriers – evaluate severity of barriers

Once barriers are identified, they should be prioritized to focus the assessment on the most significant hurdles. For that purpose, it is important to assess severity of the barriers. Assess the severity of each barrier using a simple scale, such as 1–5, where 1 means low impact and 5 indicates a severe barrier that could block key parts of the policy. Most barriers affect specific aspects of the policy rather than the whole. The assessment can be based on document reviews, expert judgement and stakeholder consultations. Refer to the [ICAT Stakeholder Participation Guide](#), chapter 8, for information on designing and conducting consultations.



Consultations with stakeholders and expert judgement can help assess the severity of identified barriers and inform their prioritization.

Following Böttcher et al. (2011), two primary methods are recommended:

- **Method 1: Simultaneous rating –**
In this approach, a group of experts or stakeholders assigns a score to each barrier simultaneously based on predefined criteria, such as ‘severity of the barrier’ and ‘impact on policy technical potential’. This is a relatively quick and intuitive method suitable for assessments with limited time or data. Once severity has been determined, barriers can be prioritized accordingly.
- **Method 2: Pairwise comparison –**
This is a more rigorous, multi-criteria decision-making tool (often based on the analytic hierarchy process). It involves comparing each barrier against every other barrier in a matrix to determine their relative importance. This method reduces subjective bias and provides a mathematically grounded ranking of barriers.

These are best conducted through structured interviews with at least five experts from politics, business/finance and academia.

For worked examples and ready-to-use templates for both methods, see [Appendix C](#), tables 5.C11 and 5.C12

Further guidance on how to account for barriers on the expected RE addition of the policy for the assessment period is provided in section 5.5.4.

5.5.3. Step 3: Identify policies that may help overcome barriers

This step focuses on identifying existing policies or actions that may either mitigate or exacerbate the barriers identified, rather than proposing new policy interventions.

For each barrier identified, identify policies or actions in the country that may overcome or increase the barrier, and describe how, and to what extent, such policies and actions may help overcome the barrier. The evaluation of the effect of the barrier is then adjusted accordingly. The end-to-end example in [Appendix E](#) illustrates how this step is applied in practice.

5.5.4. Step 4: Determine effect of barriers on technical potential for the assessment period

Determine how identified barriers affect the expected RE addition attributable to the policy over the assessment period, as follows:

1. **Determine the effect of each barrier on the expected RE addition of the policy for the assessment period:** For example, the outcome of the barrier analysis might indicate that a barrier reduces the expected RE addition of the policy for the assessment period by x per cent. The reduction can take place on two different levels, depending on the design of the policy.
 - a. **General level:** The barrier affects the entire policy (e.g., barriers that hinder the deployment of all RE technologies). In this case, the effect of the barrier on the expected RE addition of the policy for the assessment period applies to the entire policy’s impact.

b. **Technological level:** The barrier only affects one specific RE technology supported by the policy (e.g., specific barriers that hinder the deployment of solar PV installations). In this case, the effect of the barrier on the expected RE addition of the policy for the assessment period only applies to the policy's expected RE addition for the assessment period for this specific technology.

For barriers that are categorized as very severe, identify the precise aspect of the expected RE addition of the policy for the assessment period or RE resource potential to which the barrier relates (e.g., wind energy in a particular region). Reduce the impact of the policy to zero for this aspect of the expected RE addition of the policy for the assessment period.

2. **Determine overlaps between the barriers:**

Identify whether, and to what extent, the impacts of different barriers overlap. Where overlaps exist, account for these interactions to avoid double-counting their effects.

3. **Account for the effects of all barriers:**

Estimate the combined effect of all barriers on the expected RE addition of the policy over the assessment period, taking into account any identified overlaps. Where appropriate, this estimate may be accompanied by an uncertainty range to reflect uncertainty regarding the likelihood and magnitude of one or more barriers.

Table 5.3 provides a template that can be modified as needed to help users account for a variety of barriers.

Where users choose not to use the approach described in sections 5.5.1–5.5.4, they can use country-specific studies that identify barriers and account for their effect using expert judgement to assist them in their assessment. Other tools are also available, such as the GIZ barriers-to-objectives weighting method (Böttcher et al., 2011), which provides a quantitative method for evaluating barriers on a project level. Such tools could be used to account for barriers or in support of the steps outlined below.

Table 5.3. Sample template for barrier analysis

Step 1 Barrier category	Barrier description	Step 2 Severity of barrier	Step 3 Other policies addressing barrier	Step 4 Impact factor	General level/ technological level	Overlap with other barrier(s)
Specify the overarching barrier category.	Describe the specific barrier and explain how it may affect the policy.	Provide severity of barrier on a scale of 1–5, with 1 indicating low impact and 5 indicating very severe impact.	Provide analysis on whether other existing policies may help to overcome this barrier.	Provide the effect of the barrier on the technical potential for the assessment period of the policy. The technical potential for the assessment period can also be provided with an uncertainty range.	Specify whether the impact factor applies on a general level or a technological level.	Provide analysis on whether, and to what extent, the barrier overlaps with other existing barriers.



Expert judgement can support the assessment of how barriers affect the technical potential of renewable energy, drawing on existing country-specific studies.

- Estimate each barrier's impact on expected RE addition during the assessment period.
 - General level: Barrier affects the entire policy (e.g., all RE technologies).
 - Technological level: Barrier affects only certain technologies (e.g., solar PV).

If a barrier is assessed very severe, the expected RE addition should be significantly reduced. In many cases, this may result in zero addition; however, practitioners may estimate a partial reduction (e.g., 50–90 per cent) based on expert judgement and documented assumptions.
- Check for overlap between barriers and adjust for any combined effects.
- Calculate the total impact of all barriers on expected RE addition, considering overlaps. Include an uncertainty range if needed.

Use the template in table 5.3 or apply tools like the GIZ barriers-to-objectives weighting method (Böttcher et al., 2011) to support the analysis. Expert judgement may also be used.

5.5.5. Examples of accounting for other barriers

Box 5.5 provides example of accounting for other barriers for an auction policy.

Similar examples for FiTs, net metering and VRE-grid-battery storage policies are given in [Appendix C, boxes 5.C11–5.C13](#).

5.6. Summary of estimated renewable energy additions for policy examples

The examples illustrate how important it is to account for any factors that will affect the deployment of RE. Table 5.4 summarizes the results of auctions (example 1), including the adjustments made for each of the factors

accounted for, both in terms of reduced impact and the percentage of the technical potential these reductions represent.

In this case of auctions, each of the adjustments made to account for policy characteristics, financial feasibility and other barriers was of the same order – around 15 per cent of the technical potential. It can, however, vary in other cases – FiT policy, for example, where policy design characteristics have a disproportionate impact on deployment of RE. In the example given in [Appendix C, table 5.C13](#), a full 38 per cent of the technical potential was reduced by policy design characteristics. It is important to note that, in the case of FiT example, other barriers also reduced the deployment of RE significantly.

Similar summary results for other policies, including for FiTs, net metering and VRE-grid-battery storage policies are given in [Appendix C, tables 5.C13–5.C15](#).

The final estimated RE additions (MW or MWh) determined in this chapter serve as the primary activity data for calculating the total GHG emission reductions in the next chapter.

Box 5.5. Auctions (example 1) – Accounting for other barriers to refine expected RE addition of the policy for the assessment period

1. Estimate technical potential for the assessment period

2. Account for policy design characteristics

3. Account for effect on financial feasibility of RE technologies

4. Account for other barriers

In step 4, the effect of barriers on the technical potential for the assessment period is estimated. The extent of this effect is based on expert judgement:

- Lack of technical standard and limited domestic supply-chain capacity for renewable energy technologies – This barrier is categorized as very severe, indicating that deployment under the auction policy may be constrained. Based on expert assessment, this barrier is estimated to reduce the expected renewable energy additions by 5 per cent.
- Policy uncertainty due to history of ad hoc policy changes and adjustments – A reduction of 5–10 per cent (applies to total expected RE addition of the policy for the assessment period), based on the assessment of how policy uncertainty affects investor behaviour using survey data with a small representative sample of investors.
- Slow and non-transparent permit approval process – This barrier is overcome by other policy intervention to reform permit approval process. Therefore, no additional reduction is applied.
- Concerns about financial solvency of only state-owned utilities with history of defaults – Minus 8–15 per cent (general level), based on the assessment on how policy uncertainty affects investor behaviour using survey data with a small representative sample of investors.
- Insufficient availability of skilled personnel for renewable energy project development and installation – Minus 4–7 per cent (technology level), based on labour market assessment of the number of skilled personnel to install solar energy panels and industry consultations.

As the impact of the lack of skilled personnel partially overlaps with the impact of limited domestic supply chain capacity, the barrier-specific impact cannot be aggregated. Expert judgement suggests that the overlap accounts for approximately 5 percentage points. Taking this overlap into account, the combined effect of the barriers is estimated to be between 27 and 42 per cent

The barrier analysis therefore suggests that the auction policy will increase RE generation between 262 MW and 329 MW. The range represents the uncertainty associated with the identified barriers.

262–329 MW

Notes:

- Where multiple barriers interact or reinforce one another, their combined effect is assessed qualitatively through expert judgement, rather than by summing individual barrier effects.
- The reduction factors presented in this example are illustrative and based on expert judgement. Actual impacts of barriers on RE deployment may vary significantly depending on country-specific conditions and policy design.

Table 5.4. Summarized results for auctions (example 1) to increase RE additions

Step	RE addition (MW)	Adjustment	% reduction
Step 1: Estimate technical potential	640	-	-
Step 2: Account for policy design characteristics	550	-90	14
Step 3: Account for financial feasibility	440	-110	17
Step 4: Account for other barriers	338 to 374	-66 to -102	10 to 16

Chapter 6: Estimating GHG impacts of the policy ex-ante

6.1 Establish baseline and policy scenarios | 6.2 Determine method to estimate GHG impacts from renewable energy additions | 6.3 Approach 1: Estimate GHG impacts using the emissions trajectory method | 6.4 Approach 2: Estimate GHG impacts using the grid emission factor method



It is a key recommendation to:



- Select the method for estimating GHG impacts based on the assessment objectives, expected policy impact and time frame.
- Estimate the emissions trajectory using energy models where feasible; otherwise, use the GEF method when limited data is available.
- Estimate the GHG impact using a GEF calculated using the Article 6.4 methodological tool (UNFCCC 2026).

This chapter provides guidance for estimating the expected GHG impacts of RE policies before implementation. The purpose is to translate RE additions estimated in chapter 5 into expected GHG impacts over the assessment period.

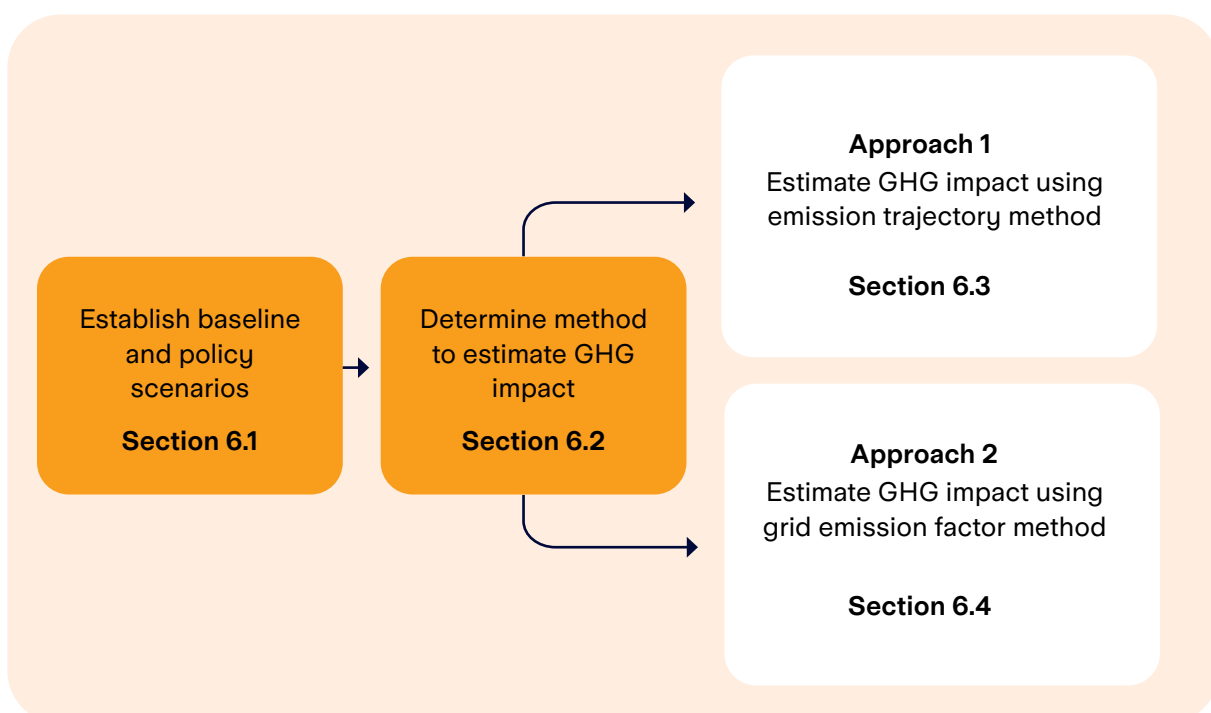
Two approaches can be used:

- Emissions trajectory method
- Grid emission factor method

The choice of method depends on power system characteristics, RE penetration, data availability and analytical capacity.

Figure 6.1 presents the steps included in this chapter.

Figure 6.1. Overview of steps in the chapter



6.1. Establish baseline and policy scenarios

To estimate avoided GHG emissions attributable to a policy, users should define:

- **A baseline scenario**, representing expected development in the absence of the policy
- **A policy scenario**, representing expected development with the policy implemented

The difference between emissions in these two scenarios represents the GHG impact attributable to the policy.

Both scenarios should:

- Use identical system boundaries
- Cover the same assessment period
- Use consistent assumptions and data sources
- Apply the same methodological assumptions



Baseline and policy scenarios should be developed before selecting the estimation method, as they provide the analytical basis for quantifying policy impacts. For more details, refer to section 4.5.2 of the [Introductory Guide](#).

Where uncertainty exists, assumptions should follow a conservative approach to avoid overestimating impacts.

6.2. Determine method to estimate GHG impacts from renewable energy additions

After defining baseline and policy scenarios, users should select an approach for estimating GHG impacts.

Two main methods can be used:

1. Emissions trajectory method

This method estimates GHG impacts by modelling the evolution of emissions over time, based on the projected electricity generation mix. It incorporates the RE additions estimated in chapter 5, and reflects how these influence the overall energy system.

The emissions trajectory can be:

- Used on its own to assess alignment with emissions targets
- Compared with the baseline scenario to estimate GHG emission reductions attributable to the policy

This method can be applied using simplified calculations or detailed energy system models.

2. Grid emission factor method

This method assumes that RE displaces electricity generated by other resources supplying the grid, and estimates GHG reductions using the emission factor of the current and expected future grid (as a result of addition of RE). It is suited for policies with smaller impacts, and uses simplified assumptions about development of the energy sector.

- The displaced emissions come from carbon-intensive grid electricity.
- To quantify this impact, the assessment applies a specific emission intensity rate that represents the electricity production being replaced by the policy.
- For grid-connected RE, the GEF serves as the baseline emission factor.

In summary, the emissions trajectory method develops a trajectory for future emissions from the electricity grid based on the expected future mix of generating technologies, whereas the GEF method assumes that the RE addition displaces grid electricity, and calculates the GHG impacts of the policy based on the emission factor of the current and expected future electricity grid.

Table 6.1 provides further information about the two methods.

It is recommended to select the GHG impact estimation method based on the assessment objectives, as well as the policy's expected impact and duration. Users should choose between the emissions trajectory method and the GEF method, considering the factors below.

Table 6.1. Brief description of the emissions trajectory method and grid emission factor method

Method	Approach	Objective	Advantages	Disadvantages
Emissions trajectory	Sectoral emissions are modelled.	- To estimate sectoral GHG emissions levels achieved after an intervention. - To estimate GHG emissions reductions from interventions, by comparing baseline GHG emissions with policy GHG emissions. - Especially suitable for larger-scale interventions.	Dynamic; accounts for interactions between the RE technologies incentivized by the policy and the electricity mix over time.	Low level of standardization; there is no standardized approach for developing emissions trajectories, and many models are commonly used (e.g., LEAP).
GEF	Emission factors reflect emissions intensity of displaced technology.	- To estimate GHG emissions reductions from interventions. - Especially suitable for single projects or other smaller-scale interventions.	- High level of calibration; Article 6.4 methodological tool (A6.4-AMT-007) describes a case-based approach for calculating GEF to ensure that project baselines remain both dynamic and strictly conservative. - Methods are widely accepted and used for project-level analysis, including through harmonization efforts of bilateral and multilateral funds. - Energy sector model not needed; may be easier to use than emissions trajectory method.	- Relatively static; methods account for future development (e.g., operating margin method), but only to a limited extent - Assumptions about the baseline scenario may be contested. - More challenging to estimate GHG impacts over longer time frames.



Refer to this guide's [assessment toolkit](#) to access Article 6.4 methodological tool (A6.4-AMT-007).

6.2.1. Impact on the power system

A policy's impact on the power system depends on several factors, including system size, the scale of RE deployment and the availability of flexibility resources. These resources include hydropower, energy storage, demand response, transmission capacity and interconnections. Power system flexibility refers to the capability of a power system to maintain continuous service in the face of rapid and large swings in supply or demand. Together, these resources determine the system's ability to integrate increasing shares of VRE while maintaining reliable and secure operation, and balancing supply and demand. The current share of VRE in the electricity mix can provide a rough indication of integration challenges, although the ability of a power system to absorb additional VRE depends primarily on its flexibility. Systems with high flexibility can integrate larger shares of variable generation with fewer operational constraints, while systems with limited flexibility may experience integration challenges even at relatively low VRE penetration levels.⁷

Energy storage is an important flexibility resource that can facilitate higher shares of VRE. In particular, grid-scale battery storage can shift electricity supply across time periods, reduce curtailment by absorbing generation that would otherwise be excess during periods of high VRE output, and support system balancing through frequency regulation, flexible ramping, and discharging during periods of high demand. However, when assessing the impacts of battery storage, users must account for round-trip losses during storage, typically in the range of 10–20 per cent, corresponding to round-trip efficiencies of approximately 80–90 per cent (Anisie and Boshell, 2019). These losses should be reflected in estimates of net electricity delivered to the grid.

The IEA (Kuwahata, Jorquera Copier and Hevia-Koch, 2024) categorizes power systems

into six phases based on their ability to integrate increasing shares of wind and solar generation (see table 6.2). These phases reflect a combination of factors, including VRE penetration levels, system size, grid infrastructure, operational practices, and the availability of flexibility resources such as hydropower, energy storage, dispatchable generation, demand response and interconnections.

In phases 1 and 2, VRE has limited system-wide impact. In phase 1, VRE deployment is typically only a small share of annual energy demand and has no immediate effect on system operation. In phase 2, minor changes to net load emerge and existing flexibility resources can handle more frequent ramping with limited operational adjustments. From phase 3 onwards, VRE begins to significantly determine system dispatch and emerging patterns such as the 'duck curve', which require systematic changes to operational logic and the active deployment of flexibility resources. In phases 4 and 5, VRE meets nearly all demand during certain periods and surpluses become structural, requiring advanced solutions including grid-forming inverters, large-scale storage, demand response and power-to-X technologies. Phase 6 represents systems where secure electricity supply is met almost entirely by VRE and storage, with seasonal and long-duration storage becoming the principal remaining challenge.

As system complexity increases with higher VRE penetration, simplified assumptions about displaced generation become less representative of actual system behaviour, particularly where marginal generation varies over time and across system conditions. The selection of the most appropriate GHG assessment methodology should therefore consider the system's current and projected VRE integration phase, alongside data availability and the purpose of the assessment:

7. In this context, VRE refers specifically to non-dispatchable solar and wind generation; hydropower (both reservoir-based and run-of-river) is excluded, as its variability typically occurs over longer (seasonal) timescales and it often provides essential grid-stabilizing services.

Table 6.2. The IEA six-phase VRE integration framework

Phase	System impact	Characteristics and integration challenges	Example countries/regions (IEA evidence)
Phase 1	No significant impact	VRE is largely insignificant at the system level. Operating parameters remain unchanged; effects are localized.	Indonesia, Philippines, Thailand, Viet Nam
Phase 2	Minor to moderate impact	Minor changes to net load. Existing flexibility (e.g., thermal or hydro) handles more frequent ramping.	India, China, United States of America (national average), Brazil, South Africa
Phase 3	VRE begins to determine operation	VRE begins to significantly influence system operation. Emerging 'duck curves' require systematic flexibility and changes in dispatch logic. ⁸	United Kingdom of Great Britain and Northern Ireland, Spain, Germany, Japan, Morocco, Jordan
Phase 4	High impact	VRE meets almost all demand during certain periods. Advanced operational and regulatory solutions (grid support technology such as grid-forming inverters) are needed.	Ireland, Portugal, Chile, Uruguay, Greece
Phase 5	Surplus management	Significant VRE surplus occurs throughout the year. Requires massive demand response, storage and power-to-X solutions.	Denmark, South Australia (state-level)
Phase 6	Very high-VRE systems	Secure electricity supply is met almost entirely by VRE and storage. Challenges include seasonal/long-duration storage and seasonal balancing.	Emerging (islands or niche 100 per cent RE)

Source: Adapted from Kuwahata, Jorquera Copier and Hevia-Koch (2024).

Notes:

- Country examples are illustrative and based on the IEA (Kuwahata, Jorquera Copier and Hevia-Koch, 2024) global assessment of VRE integration. Countries may move between phases as renewable shares and system flexibility evolve.
- VRE integration phases depend on operational impacts rather than renewable share alone. For example, Brazil remains in phase 2 due to large hydropower flexibility, while Jordan has reached phase 3 because solar generation strongly affects daily system operation.
- High-VRE systems such as Denmark and Ireland often experience instantaneous VRE penetration above system demand, requiring solutions for system strength, inertia and balancing.

8. The 'duck curve' refers to the shape of the daily net load profile (total electricity demand minus VRE). It is characterized by a significant midday drop in net demand when solar generation is at its peak, followed by a steep, rapid ramp-up in the evening as solar output vanishes while consumer demand peaks.

- **GEF method:** Generally more suitable for systems in phases 1 and 2, where VRE penetration is relatively low and does not substantially alter marginal generation or dispatch patterns. This method applies an average emission intensity and is appropriate where the generation mix and dispatch are relatively stable.
- **Emissions trajectory method:** More appropriate for systems in phase 3 and above, where VRE increasingly determines system operation and the generation mix evolves dynamically over time. This method captures marginal emission intensities and is better suited to systems where displaced generation varies significantly across time periods and operating conditions.

6.2.2. Intervention time frame

Interventions with shorter time frames (e.g., single projects or policies with shorter time frames) usually have a smaller impact on the energy system, whereas interventions with longer time frames are likely to have a bigger impact.

Users should also decide whether to estimate total GHG emissions (i.e., the GHG emissions level), or GHG emissions reductions achieved by the policy, based on the objectives of the assessment:

- **GHG emissions level:** This is especially appropriate for determining whether policies are on track to meet goals such as NDCs or RE targets, and to inform goal-setting. The emissions trajectory method should be used for meeting these objectives as the GEF method is not designed for these purposes.
- **GHG emissions impacts (reductions):** This is appropriate for assessing the effectiveness of policies, improving their design and implementation, and reporting on progress – for example, in the context of achieving NDCs. Either the emissions trajectory method or the GEF method can be used to meet these objectives and the choice should align with the VRE integration phase of the system (i.e., the GEF method

for phases 1–2 and the emissions trajectory method for phase 3 and above).

If the assessment results will be used for GHG accounting of an NDC, the base year should match the NDC base year and targets. Input data such as activity levels, emission factors and socioeconomic figures should also be consistent with those used for setting NDC targets and reporting under the Paris Agreement.

When using the GEF method, users should ensure that the underlying fossil fuel emission factors (e.g., for coal, gas or oil) are consistent with the latest IPCC guidelines and the values applied in the national GHG inventory. This ensures that the policy's impact is accurately reflected in the country's progress towards its NDC mitigation targets.

- **Refinement to GEF in case of battery storage policies:** Users should note that VRE primarily displaces 'marginal' fossil fuel plants (usually gas, or coal peaking plants in rare cases) rather than the 'average' grid mix. Usually, when solar or wind is added to a grid, the marginal plant, which is the most expensive or 'flexible' plant running in the grid (typically a gas plant) is turned off. In this case, instead of using an unadjusted average GEF, users must use the combined margin (CM) approach of the Article 6.4 mechanism's methodological tool (A6.4-AMT-007) (UNFCCC 2026). This approach involves the use of dynamic operating margin (OM) calculations (such as the dispatch data OM) that track hourly grid dispatch to capture real-time displacement of marginal plants. This ensures that avoided CO₂ calculations are based on the specific fossil fuel units actually replaced, rather than an average of the whole system.



The Article 6.4 mechanism's methodological tool can be accessed from this guide's [toolkit](#).

- Furthermore, for modern electricity systems with high clean energy penetration, users must apply the tool's specific case 2 rules. This ensures that periods when zero-emission generation or battery storage are

on the margin are accurately accounted for, blending the dynamic OM with a downward-trending build margin (BM) using conservative weighting factors. Please note that solar and wind projects are treated as intermittent generation under Article 6.4 rules, even when paired with battery storage.

6.2.3. Data requirements for renewable energy policy assessments

As elaborated in this chapter, in case of RE, two main approaches are used for GHG emissions estimation: the emissions trajectory approach and the GEF approach. The data requirements vary across the two approaches, as indicated in table 6.3.

6.2.4. Sources for obtaining or estimating data

It is recommended that users prioritize country-specific data when estimating GHG impacts. Potential data sources include:

- **National sources:** A country's ministry of energy, national statistics division, national energy research institutes and other relevant government agencies
- **International sources:** Organizations such as IEA and IRENA

If country-specific data are unavailable, users may:

- Use regional data as a proxy
- Make expert-informed estimates where necessary



Expert judgement can support the estimation of data required for GHG emissions assessment when country-specific data are unavailable.

6.3. Approach 1: Estimate GHG impacts using the emissions trajectory method

This section outlines how to estimate GHG emissions over time for both the policy and baseline scenarios. Users who are not using the emissions trajectory method may move on to section 6.4, using the GEF method.

An emissions trajectory shows how GHG emissions are expected to change over time. The emissions trajectory can be used:

- On its own, to check if the emissions path aligns with the emissions reductions target implied by planned or targeted RE deployment
- With a baseline scenario, to estimate the GHG reductions achieved by a policy

The same method should be used to estimate emissions for both the policy and the baseline scenarios.



Key recommendation:

Use energy system models whenever possible. Energy models are the preferred tool for implementing the emissions trajectory method, particularly for power systems in phase 3 and above, where VRE begins to significantly influence system operation and dispatch patterns.

Compared with the GEF method, energy system modelling provides more accurate estimates because it identifies the specific fossil fuel generation displaced by RE and accounts for future changes in the power system, such as plant retirements, new capacity additions and evolving operational constraints.

Furthermore, modelling produces complete emissions trajectories, which are necessary for tracking progress towards NDCs and for reporting under the ETF.

Energy models are particularly recommended for systems in phase 3 and above, where increasing VRE penetration leads to greater grid complexity and system-wide interactions. When data availability or analytical resources are limited, simpler methods described in section 6.3.2 may be used.

Table 6.3. Data and parameters typically used in estimating GHG emissions

Approach	Data type	Examples of data and parameters
Emissions trajectory method (energy system modelling) <i>Recommended for systems in phase 3 and above, where VRE significantly influences system operation</i>	Macroeconomic and demand drivers (baseline)	- Gross domestic product (GDP) growth (primary economic driver) - Energy intensity of GDP over time - Population and growth rate - Electricity demand per capita for the assessment period - Electrification of end uses (e.g., electric vehicles, electric heating)
	Electricity system and grid (baseline and policy)	- Total electricity demand for the assessment period - Electricity generation mix (planned capacity additions and retirements) - Transmission and distribution (T&D) losses - Auxiliary consumption (difference between gross and net generation) - Technology investment costs and fuel prices (where applicable) - Interconnection capacity⁹ - Energy storage capacity (e.g., battery storage, pumped hydro)
	System operation and plant-specific	- Net quantity of electricity generated and delivered to the grid - Amount of specific fuel types consumed - Average net efficiency of power plants - Net calorific value of various fuel types - CO₂ emission factors of various fuel types - OM and BM data for GEF calculations - Emerging practice includes recorded VRE curtailment data (if available)
Applicable to both approaches (emissions trajectory and GEF methods)	Storage performance data	Storage round-trip efficiency and annual degradation rate

9. This refers to the maximum amount of electricity that can be transferred between two power systems or grid areas through transmission links. It is usually expressed in MW.

If the assessment will be used for reporting under the ETF, ensure that:

- The time frames (start and end years) used for RE policy projections are consistent with the NDC time frame to ensure alignment with national climate targets and ETF reporting cycles.
- Where possible, these time frames should also align with national energy sector projections to ensure consistency across different government planning documents.
- Key input assumptions (e.g., GDP growth, energy intensity and population) are consistent with the official assumptions used in national GHG projections and other sectoral reports.
- The projections inform the indicators selected by the country to track progress towards achieving its NDC, in alignment with ETF reporting requirements.

6.3.1. Estimate the emissions trajectory using an energy model

A range of analytical models can be used to assess the impacts of RE policies. These models differ in their purpose, level of complexity, data requirements and the type of questions they are designed to answer. Some models are used to analyse long-term energy system pathways and technology choices, while others focus on estimating the GHG mitigation potential of specific policies or measures. The models listed in table 6.4 are examples of tools that have been widely used in energy and climate policy analysis, including in developing countries. The table provides an overview of the key characteristics of these models to help analysts and policymakers identify tools that may be suitable for assessing RE policies in their national context. The selection of a model will depend on the policy questions being analysed, data availability and the technical capacity of the institutions conducting the assessment.

Table 6.4. Examples of models that can be used to assess RE policies

Criterion	TIMES	LEAP	Energy-PLAN	PROSPECTS+	GACMO	OSeMOSYS	MESSAGEix
Developer	IEA-ETSAP (IEA Technology Collaboration Programme)	Stockholm Environment Institute	Aalborg University	New Climate Institute (with support from Climate Works Foundation)	UNEP-CCC	KTH Royal Institute of Technology and partners	International Institute for Applied Systems Analysis (IIASA)
Purpose of model	Energy system optimization and planning	Energy policy analysis and scenario development	Simulation of national energy systems	Assessment of policy impacts on emissions	Assessment of mitigation measures and their emissions reduction potential	Least-cost energy system planning	Integrated energy system and climate scenario analysis
Type of model	Energy system planning model (optimization)	Energy system planning model (scenario simulation)	Energy system simulation model	Mitigation assessment model	Mitigation assessment model	Energy system planning model (optimization)	Energy system planning model (optimization)
What the model is commonly used for	Detailed analysis of energy system transitions and technology choices	Development of national energy scenarios and evaluation of energy and climate policies	Analysis of systems with high shares of RE, including storage and system balancing	Estimating GHG impacts of policies and mitigation actions	Estimating mitigation potential and marginal abatement costs of measures	Identifying least-cost energy pathways and long-term energy planning	Long-term energy and climate mitigation scenario analysis

Criterion	TIMES	LEAP	Energy-PLAN	PROSPECTS+	GACMO	OSeMOSYS	MESSAGEix
Sectors covered	Energy supply and demand sectors	Energy supply and demand sectors	Electricity, heating, transport	Economy-wide policies and measures	Energy and other mitigation sectors	Energy supply and demand sectors	Energy system and related sectors
Technology coverage	Very detailed representation of energy technologies	Wide range of energy supply and demand technologies	Electricity generation, heating, transport and storage technologies	Policies and mitigation measures	Individual mitigation technologies and measures	Detailed representation of energy supply technologies	Detailed energy technologies and system interactions
Cost calculations	System cost optimization	Investment and operating costs	Energy system cost calculations	Policy mitigation impacts	Mitigation costs and marginal abatement cost curves	System cost optimization	System cost optimization
Modelling environment	Programming environment	Graphical interface	Stand-alone software interface	Spreadsheet-based	Spreadsheet-based	Programming environment	Programming environment
Technical expertise required	Advanced modelling expertise required	Limited technical expertise required	Moderate technical expertise required	Limited technical expertise required	Limited-moderate technical expertise required	Moderate technical expertise required	Advanced modelling expertise required
Free or to purchase	Core model free; requires licensed modelling software	Free for developing countries	Free	Free	Free	Open source	Open source

The RE addition calculated in chapter 5 should be used as an input to ensure the emissions trajectory reflects the expected RE deployment under the policy.

Model selection:

- **For quick ex-ante screening (phases 1 and 2):** Tools such as GACMO and PROSPECTS+ can be useful starting points. These tools are typically easier to use because they operate in spreadsheet environments and generally require fewer data inputs. They are well suited for estimating the mitigation potential and emissions impacts of specific policies or measures.
- **For national energy planning:** Models such as LEAP, OSeMOSYS and TIMES energy system model are commonly used to analyse long-term energy system pathways and the impacts of energy policies on

emissions, technology deployment and system costs. The Long-range Energy Alternatives Planning System is widely used in developing countries due to its structured interface and flexibility for scenario analysis.

- **For analysing systems with higher shares of VRE:** Models such as EnergyPLAN and detailed energy system models such as OSeMOSYS and MESSAGEix can be used to explore system balancing, storage needs and other integration challenges associated with higher shares of solar and wind power.
- **For transparency and reporting under the ETF:** Open-source models such as OSeMOSYS and MESSAGEix offer a high level of transparency because their underlying model structures and source code are publicly available and can be reviewed by third parties.

6.3.2. Determine the emissions trajectory using method for limited data availability

Where data are limited, users can follow these three steps:

Step 1: Estimate future electricity demand

Understanding how electricity demand will grow is the first step in projecting electricity-related emissions. You can use one of the following methods or a combination:

1. Use national electricity demand forecasts from reliable sources such as the ministry of energy, national energy research institutes or international organizations such as IEA. Prefer nationally accepted data that is backed by the Government.
2. If national data are unavailable, use regional forecasts and adjust them. For example, apply regional electricity demand growth rates to your country's past demand data. However, make sure the regional trends reflect national conditions.
Example: IEA data for North America include Canada, the United States of America and Mexico. Using this average for Mexico could underestimate growth, since RE levels in Mexico are much lower than in the United States of America or Canada.
3. Estimate future electricity demand using simplified drivers. Where official national or regional forecasts are unavailable, users can build a demand projection by linking electricity consumption to the following key demographic and economic indicators:
 - **Use historical growth trends:** Extend past electricity demand data using a linear trend or another method that reflects how demand has changed over time.
 - **Link demand to population growth:** Estimate future demand by multiplying current per capita electricity use by projected population growth.
 - **Link demand to GDP growth:** Assume electricity demand grows with GDP. Adjust for possible decoupling (e.g., from energy efficiency improvements) by making appropriate assumptions.

- **Link demand to both population and GDP growth:** This combined approach is frequently used to provide a more robust estimate. It accounts for the simultaneous impact of a growing population and increasing economic activity, often using elasticities to reflect how demand responds to changes in both drivers.

Step 2: Project future electricity generation

The next step is to estimate the total electricity that must be generated, accounting for T&D losses and the electricity used by power plants themselves, using the following equation:

Equation 6.1. Total electricity generation

$$\text{Total electricity generation (MWh)} = \frac{\text{Total electricity demand}}{(1 - \text{Transmission and distribution loss (fraction)} - \text{own use (fraction)})}$$

Historical data on T&D losses (as a percentage of total generation) are available for most countries in the World Development Indicators database (World Bank Group). Table 6.5 provides regional five-year averages, along with minimum, maximum and median values for individual countries. If country-specific data are not available, users can apply regional averages.

To estimate T&D losses in absolute terms (MWh), multiply the projected electricity demand by the percentage of T&D losses.

The average global share of electricity used by power producers for their own operations is about 5 per cent of total generation. However, this varies widely by country, depending on the types and ages of power plants.

Step 3: Project future electricity mix

Next, estimate how the electricity mix will change over time, taking into consideration the estimated RE additions from the policy scenario. Start by identifying how much electricity is currently generated by each technology. These data can be found in national sources (such as the energy ministry) or international databases.

Table 6.5. Transmission and distribution losses (percentage of output)

Region	T&D losses (percentage of output), average (2019–2023)
East Asia and Pacific	~6–8%
Europe and Central Asia	~6–8%
Middle East and North Africa	~9–11%
Sub-Saharan Africa	~10–14%
Latin America and Caribbean	~10–15%
Organisation for Economic Co-operation and Development (OECD) members	~4–7%
Least Developed Countries: United Nations classification	~12–18%
World	~7–9% [†]
Minimum (Singapore)	~0.23% in 2023 [*]
Median (approx.)	~9–11% [*]
Maximum (e.g., Togo)	~65% [*]

[†] The world average T&D loss rate has generally trended lower than historical 2010–2014 values (8.2%) based on recent data distributions in WDI (World Development Indicators).

^{*} Singapore had one of the lowest reported T&D losses globally (~0.23% in 2023), while Togo remains among those with the highest losses (above ~65%) (HelgiLibrary).

Notes:

- Regional averages are derived from recent World Development Indicators country data, indicator: Electric power transmission and distribution losses (percentage of output). Values represent typical ranges observed during between 2019 and 2023, and may vary by data availability and year clustering across countries.
- Europe and Central Asia: This World Bank regional grouping includes Western and Eastern Europe, and Central Asia.
- The OECD grouping overlaps geographically with Europe and other regions due to membership, rather than pure geography.

To project the future mix, choose one or combine the following approaches:

1. **Keep the current technology shares unchanged:** Assume that the share of each technology in the electricity mix stays the same in the future. Use the most recent data available and scale all technologies up or down based on changes in total electricity demand.

Note: This assumption is primarily relevant for the baseline scenario when there is no clear information about future energy mix changes. For the policy scenario, users must adjust these shares to include the specific RE additions expected from the policy being assessed.

2. **Extend past trends in technology shares.** Use historical trends in the electricity mix to project future shares. Be cautious with long time frames, as past high growth rates may not continue. Adjust the projections as needed to reflect factors such as those listed in table 6.6.

Note: While useful for establishing a baseline scenario, this approach must be modified for the policy scenario to reflect the additional RE generation resulting from the policy intervention.

3. **Assume some technologies will grow or decline more than others.** This approach is realistic under the following conditions:
 - a. There is clear evidence that certain technologies will become more important in the future. For example, national plans may show a transition away from coal-fired generation because the national climate strategy prioritizes the deployment of cleaner energy sources.
 - b. System changes are making some technologies more suitable. For instance, as solar and wind increase, the grid may need more flexible sources instead of baseload ones such as coal.

Table 6.6. Factors to consider when assuming a continuation of historical trends in the electricity mix

Factor	Example and brief explanation	Reference
Investment in electricity generation technologies	Short term The time needed to develop, build and commission power plants varies across technologies. Whereas some may have lead times of months, others may take years. Comparing trends in investment costs for different technologies can also provide a short-term indication of the kinds of power plants that will likely be built in the future.	Historical investment: McCrone et al. (2018); Cheung et al. (2019) (private); IRENA 'Investment Trends' Technology lifetimes: Eureka et al. (2016); Lorenczik and Keppler (2020)
	Mid to long term The lifetime of a power plant varies across technologies. Whereas wind and solar have lifetimes of at least two decades, conventional power plants, such as coal or nuclear, may have longer ones. Recent investment in electricity generation technologies can give a rough indication of the kind of power plants a country has in the pipeline and an overview of how the future electricity share would look in the mid to long term.	

Factor	Example and brief explanation	Reference
Status of abundance of natural resources in the region/ country	Renewable resources While renewable resources are geographically constrained, significant additional capacity may still be realized in regions with existing deployment through repowering, efficiency improvements and upgrades to existing installations. For example, early wind turbines with capacities of a few hundred kilowatts can be replaced by modern multi-megawatt turbines, substantially increasing output without expanding the number of sites. By comparing resource maps and existing power plants, users can gain an indication of the potential for future additions of a given technology. Conventional resources Studies have shown that countries with high production of fossil fuels – and thus high energy self-sufficiency – have the lowest share of RE generation. Thus, it is likely that if historically a country has had an abundance of fossil fuel resources, its VRE addition is likely to lag behind.	National or international databases on natural resources (see Appendix C, tables 5.C3 and 5.C4)
Historical and projected fuel prices	As a main component of LCOE, fuel prices may indicate if it is economically attractive to develop and invest in a particular technology. An indication of historical and projected costs of fuels may give an indication of the financial feasibility of certain technologies over others (together with the technology's LCOE).	Ilas et al. (2018); Lazard (2018); IRENA (2019a); see also Appendix C, table 5.C1
Existing subsidy schemes for certain technologies	Similar to fuel prices, subsidies influence a technology's LCOE. Subsidies include policies that artificially decrease energy prices or production costs of power generation technologies. If a particular technology is subsidized, its price is artificially lowered. This results in subsidized technologies having an economic advantage over non-subsidized ones. For example, the existence of fossil fuel subsidies may hinder the transition to RE generation technologies because subsidies result in underpricing of fossil fuel generation. Likewise, if one renewable generation technology is subsidized while another is not, the non-subsidized technology will be less economically attractive, thus hindering its implementation. In this sense, having an overview of existing subsidies in a country may give an indication of a country's future energy mix.	Shirai (2017); IEA (2025c)

Factor	Example and brief explanation	Reference
Type of system and system changes to accommodate higher shares of VRE	As the share of VRE increases in an electricity system, it is important to allow for measures that help balance supply and demand. Such measures are called “flexibility measures” and can include the following: Demand-side management: These measures reduce disturbances in a grid, helping to balance demand and supply. As the share of VRE generation increases, supply depends to a greater extent on the availability of natural resources (e.g., wind and sun), thus requiring greater flexibility. These measures include peak shaving, valley filling, load shifting and conservation. Energy efficiency and demand reduction policies: Energy demand reduction is essential for increasing the share of renewables in the energy system. Absolute reduction of energy consumption leads to lower electricity demand, meaning that less RE is needed to achieve full decarbonization. Energy efficiency and demand reduction policies: Energy demand reduction is essential for increasing the share of renewables in the energy system. Absolute reduction of energy consumption leads to Energy storage: Given the variability of natural resources, electricity storage also helps balance supply and demand. Energy that is produced when demand is low can be used later, when demand increases. Hydro capacity can also be used as storage. T&D infrastructure (including interconnection): Increasing VRE electricity generation may require additional transmission and distribution infrastructure. VRE power plants are located in areas where the resource is available, but these may not always correspond with locations where the electricity will be consumed. Also, an electricity system that is interconnected with other systems provides greater flexibility. VRE in grid codes: Grid codes specify the required behaviour of a generator in the electricity system. If VRE sources are integrated, the system is better prepared to deal with disturbances. Electricity markets: These include capacity market mechanisms and market-based measures for energy storage and demand-side management.	Recent capacity additions: Whiteman et al. (2019) can be used to check factors that may affect changes in an energy system Energy efficiency: Castro-Alvarez et al. (2018) General: Liesch et al. (2018); own analysis adapted from de Villafranca Casas et al. (2018)

When developing the emissions trajectory, it is important to consider how different policies in the country interact. If the policy is part of a broader energy strategy or other policies affect the power mix, factor in how these may change the projected electricity generation.



After projecting future electricity demand (step 1) and mix (step 3), review your assumptions such as growth rates and mix changes through consultation with national energy experts.

Step 4: Estimate total CO₂ emissions from electricity generation

To calculate emissions, apply technology-specific emission factors to the electricity generation mix to estimate the emissions level, using one of the following approaches.

Use future technology-specific emission factors from national studies or other reliable sources. These factors do not change significantly with shifts in the electricity mix and can be taken from existing sectoral modelling studies.

To calculate technology-specific emission factors from historical data (tCO₂/MWh), apply Equation 6.2 using figures from the IEA CO₂ Emissions from Fuel Combustion database or national statistics.

Equation 6.2.

$$EF_i^t \left[\frac{tCO_2}{MWh} \right] = \frac{TE_EG_i^t [tCO_2]}{EG_i^t [MWh]}$$

Where:

EF: The emission factor of an electricity generation technology in a given year

TE_EG: The total emissions from electricity generation of a given technology

EG: The electricity generated

i: The fossil fuel used for electricity generation (i.e., coal, lignite, gas or oil)

t: The year the electricity was generated

Table 6.7 shows average emission factors by plant type and region.

Table 6.7. Typical direct CO₂ emission factors of power plant technologies (2019–2023)

Power plant technology	Average emission factor (tCO ₂ /GWh)
Anthracite-fired power plant	980 ¹⁰
Bituminous coal-fired power plant	900
Sub-bituminous coal-fired power plant	950
Lignite-fired power plant	1050
Natural gas-fired power plant	400–450
Oil-fired power plant	750–900

Notes:

- Emission factors represent direct CO₂ emissions from fuel combustion only.
- Values are global averages reflecting recent operational performance; regional variation may occur due to fuel quality, plant efficiency and operating conditions.
- Where country- or plant-specific data are available, those should be used in preference to default values.

Sources: Shukla et al. (2022); IEA (2023); IEA (2024).

10. Based on Egglestone et al. (2006). Anthracite: 98,300 kg CO₂/TJ (default range: 94,600–101,000).

Coal-and oil-fired power plants exhibit the highest CO₂ intensities, while natural gas plants emit substantially less per unit of electricity generated. These default emission factors provide a robust basis for policy impact assessment where detailed country-specific data are unavailable. Users interested in updated regional emission factors can source them from the IEA (2024) database, which is available on a subscription basis.

Estimate future emission factors using the following approaches:

- 1. **Assume that they remain constant** – that is, that there is no improvement in the energy efficiency of technologies and that the fuel composition stays the same.
- 2. **Assume improvements**, if retrofitting or new, more efficient plants are planned.

See table 6.8 for expected efficiency improvements. According to the IEA World Energy Outlook (2018), for example, expected efficiency improvements for 2016–2030 are:

- **Coal:** 1–10 per cent efficiency gains
- **Gas:** 5–10 per cent (or more if upgraded to combined cycle)
- **Oil:** Assume no significant improvement

See table 6.8 for more updated information, depending on the current technology in use in the country.

Finally, apply the emission factors to each technology’s share of the mix to calculate the annual emissions (in tCO₂e) for each year in your trajectory.

Table 6.8. Future efficiency outlook for coal, gas and oil power plants

Technology	Fuel type	Expected efficiency	Time frame	Notes	Source
Global average	Coal	~33%	Present	Current global average	GE Vernova (Hitchin, 2018)
Ultra-supercritical (USC)	Coal	42–45%	Present–2030	High-efficiency existing tech	GE Vernova (Hitchin, 2018)
HELE technologies	Coal	47.5–49%	2030–2040	High efficiency, low Emissions	FutureCoal (no date)
Integrated gasification combined cycle (IGCC)	Coal	Up to 50%	2030–2045	Advanced, limited deployment	World Nuclear Association (2021)
Simple-cycle gas turbine	Gas	35–42%	Present	Basic gas turbine systems	Woodway Energy (2024)
Combined-cycle gas turbine	Gas	56–64%	Present	Standard modern configuration	American Society of Mechanical Engineers (Winters, 2023)
Advanced combined-cycle gas turbine	Gas	≥65%	2030–2035	R&D improvements	NREL (Mirletz et al., 2024)
Future R&D targets	Gas	65–68%	2035–2045+	With high-temp turbines	NREL (Mirletz et al., 2024)

Technology	Fuel type	Expected efficiency	Time frame	Notes	Source
Global average	Oil	~36–37%	Present	OECD & non-OECD average	IEA (Taylor et al., 2008)
Country-specific range	Oil	23–43%	Present	Efficiency varies widely	IEA (Taylor et al., 2008)
Future outlook	Oil	Minimal improvement	Ongoing	Limited due to phase-out	IEA (Taylor et al., 2008)

6.3.3 Calculate avoided GHG emissions (if needed)

Finally, total emissions reductions from the policy are calculated by subtracting emissions in the policy scenario from emissions in the baseline scenario. The resulting difference represents the annual avoided GHG emissions attributable to the policy.

To ensure consistency and transparency, this calculation should be performed using the same system boundaries, emissions sources and metrics defined in earlier steps. Results are typically presented on an annual basis but may also be aggregated over the full assessment period to estimate cumulative emissions reductions.

Box 6.1 provides an example of estimation of GHG reductions from an RE policy as the difference between the policy scenario emissions trajectory and the baseline scenario emissions trajectory (using proxies because of limited data availability)



Finally, when reporting the assessment results, users can refer to the Assessment Reporting Template, available for download in the [Templates](#) section.

6.4. Approach 2: Estimate GHG impacts using the grid emission factor method

This section outlines how to assess the GHG impacts of a policy or project by calculating the GEF using the Article 6.4 methodological tool, A6.4-AMT-007 (Emissions from electricity generation and consumption) (UNFCCC, 2026).

6.4.1. Calculate the grid emission factor using the Article 6.4 tool (A6.4-AMT-007)

The tool replaces the flexibility of the Clean Development Mechanism with a strict, case-based CM approach to ensure conservative and dynamic baselines.

1. **Case-based approach:** Calculations must be clearly separated based on the type of emissions being estimated to ensure a conservative estimate:
 - **Case 1 (project and leakage emissions):** When calculating the emissions footprint of electricity consumed by the project from the grid, the user must apply case 1. This requires applying the upper limit of the uncertainty interval of the emission factor, ensuring the project's footprint is not underestimated.
 - **Case 2 (baseline emissions):** When calculating the grid emissions displaced by the project's clean electricity generation, users must apply case 2. This requires determining uncertainty at the lower limit of the 95 per cent confidence interval relative to the central estimate, preventing the over-crediting of emission reductions.
2. **Application of CM:** The GEF must be determined using the CM emission factor. The CM is a dynamic weighted average of two specific grid metrics:
 - **OM:** Represents the emissions intensity of the existing power units currently operating on the grid.

- **BM:** Represents the emissions intensity of the newest power plants being added to the grid.



Refer to this guide's toolkit section to access the [Article 6.4 methodological tool \(A6.4-AMT-007\)](#).

- Refinement for VRE and battery storage integration:** While VRE typically displaces 'marginal' fossil fuel plants (such as flexible gas peakers) rather than the average grid mix, the user cannot isolate the marginal plant by solely using the OM. Under A6.4-AMT-007, the strict CM method (blending the OM and BM) is mandatory

for baseline calculations to prevent over-crediting. Furthermore, under current rules, electricity generated by solar and wind must be classified as an intermittent source when determining the applicable scenarios, regardless of whether the plant is integrated with a battery energy storage system.

Emission factor modelling can also be used to calculate GEFs; however, it relies on statistical models and historical data. Therefore, it is not suitable for capturing future changes in the grid. A note on emission factor modelling is included in [Appendix D \(6.D2\)](#).

Box 6.1. Example of GHG Reduction Estimation Using Emissions Trajectories

Example – GHG emissions reduction from RE policy using the emissions trajectory method with limited data availability

When data availability in a country is limited, users can estimate emissions reductions from RE policies using proxies. In this example, the country under assessment has neither an estimate of future electricity demand nor a baseline emissions scenario. The period of assessment is from the last current available year until 2030. In this example, calculations are shown only for 2030; in reality, they can (and should) be applied to intermediate years, as needed.

1. Estimate baseline scenario emissions trajectory

Step 1: Project future electricity demand

Future electricity generation can be estimated by taking electricity demand per capita and future population projections as proxies, and assuming transmission and distribution losses.

The first step is to estimate current electricity demand per capita in the country by using current (or last available year) data for total electricity demand and population. Total electricity demand and total population per country can be obtained from international sources (such as the IEA statistics data browser, the Enerdata "Global energy statistical yearbook", World Bank population data or United Nations population data) or national sources (such as ministries of energy, or departments for data and statistics). For most countries, time series of electric power consumption per capita are readily available. For a hypothetical country, electricity demand per capita in 2017 is calculated as follows:

$$\text{EDpC [kWh/capita]} = \text{TED [kWh/year]} / \text{Pop [capita/year]}$$

$$\text{EDpC}_{2017} = (12 \times 10^{10} \text{ kWh/year}_{2017}) / (40 \times 10^6 \text{ capita}_{2017}) = 3,000 \text{ kWh/capita}$$

where EDpC is electricity demand per capita, TED is total electricity demand, Pop is total population and t is the year.

For future years, a range can be estimated by using the following assumptions:

- Electricity demand per capita will remain constant (one end of the range).
- Historical trends will continue in the future (other end of the range).

If historical data indicate that electricity demand per capita in a country has significantly increased or decreased in the past years, it is preferable to assume a continuation of this trend. To adapt the current EDpC_t , first estimate the growth rate of the past years GR_t .

For our hypothetical country, these are the historical trends and estimated growth rates

t (year)	2005	2010	2015	2017
EDpC_t (kWh/capita)	2,300	2,600	2,900	3,000
GR_t (%/year)	—	2.48	—	2.24

Note: Growth rates are given for the periods 2005–2010 (2.48), and 2005–2017 (2.24).

The compound annual growth rate (GR_t) is estimated using the following formula:

$$\text{GR}_{t_1-t_2} = [(\text{EDpC}_{t_2} / \text{EDpC}_{t_1})^{1/(t_2-t_1)} - 1] \times 100$$

The compound annual growth rate between 2005 and 2010 is:

$$\text{GR}_{2005-2010} = [(2,600 \text{ [kWh/capita]}_{2010} / 2,300 \text{ [kWh/capita]}_{2005})^{1/(2010-2005)} - 1] \times 100 = 2.48\%$$

The average growth rate for the entire period (between 2005 and 2017) is then:

$$\text{GR}_{2005-2017} = [(3,000 \text{ [kWh/capita]}_{2017} / 2,300 \text{ [kWh/capita]}_{2005})^{1/(2017-2005)} - 1] \times 100 = 2.24\%$$

Energy sector experts from national universities are consulted, and the consensus is that energy demand is likely to grow at 2.2% per year.

To estimate the future emissions, we multiply the EDpC range by the projected population (Pop). World population prospects are available from the United Nations up to 2100. The population in our country is expected to increase from 40 million in 2017 to 45 million in 2030. Thus, the future total electricity demand (TED) range in 2030 is estimated as follows:

- **Lower end – assuming electricity demand per capita will remain constant**

$$\text{TED}_{2030}^{\text{min}} = 3,000 \text{ [kWh/capita]}_{2017} \times 45 \times 10^6 \text{ capita} \times 1 \text{ GWh}/10^6 \text{ kWh} = 135,000 \text{ GWh}$$

- **Upper end – assuming electricity demand per capita will continue increasing with the same growth rate as in the past**

$$EDpC_{2030} = EDpC_{2017} \times (1 + GR_{2005-2017})^{(2030-2017)}$$

$$EDpC_{2030} = 3,000 \text{ [kWh/capita]}_{2017} \times (1 + 2.2\%)^{13} = 4,002 \text{ [kWh/capita]}_{2030}$$

$$TED_{2030}^{\max} = 4,002 \text{ [kWh/capita]}_{2030} \times 45 \times 10^6 \text{ capita} \times 1 \text{ GWh}/10^6 \text{ kWh} = 180,074 \text{ GWh}$$

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Share (%)	17	10	40	5	10	10	5	3	0

Step 2: Project future electricity generation

Future electricity generation is the sum of electricity demand, transmission and distribution (T&D) losses, and own use of electricity by generators.

For our hypothetical country, we will assume 6.2% T&D loss (based on Section 6.2.2) and 5% of own use. To estimate total electricity generation (TEG), we simply apply equation 6.1:

$$\begin{aligned} TEG_{2030}^{\min} &= TED_{2030}^{\min} / (1 - T\&D_loss[\%] - OwnUse[\%]) \\ &= 135,000 \text{ GWh} / (1 - 11.2\%) \\ &= 152,027 \text{ GWh} \end{aligned}$$

$$\begin{aligned} TEG_{2030}^{\max} &= TED_{2030}^{\max} / (1 - T\&D_loss[\%] - OwnUse[\%]) \\ &= 180,074 \text{ GWh} / (1 - 11.2\%) \\ &= 202,786 \text{ GWh} \end{aligned}$$

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Share (%)	17	10	40	5	10	10	5	3	0

Step 3: Estimate the development of technologies in electricity mix

The next step is to break down total electricity generation into generation technologies. To estimate the future energy mix, one can use the current energy mix (or that of the last available year). This information can be obtained from national sources (e.g. ministry or department of energy) and international sources.

For our hypothetical country, the electricity generation mix in 2017 (last available year) comprises:

For the future electricity mix up to 2030, we will consider the following factors (see Table 6.6):

In our hypothetical country:

- No investment has been made in biomass, oil or geothermal electricity generation in the past 5 years; for nuclear, no investment has been made in the past 20 years,

- The current generation technologies under construction include gas, solar PV and wind,
- We know (from the national resources database) that there is potential for solar PV, geothermal, wind and hydropower generation,
- Subsidies exist for oil, coal and gas generation,
- Historical costs for oil, gas and coal have been continuously increasing in the past 20 years. Future projections from international sources indicate that prices will continue to increase in the near future.

Based on the information above, we can assume that no new nuclear power plant will be built between 2017 and 2030 (thus, the share for nuclear will slightly decrease); the share for coal, oil, biomass or geothermal will likely not increase (it might slightly decrease); electricity generation from solar PV, wind and gas will slightly increase; and hydropower generation could remain steady or even increase, as there is still potential in the country. Therefore, we assume the following share for 2030:

Finally, the electricity generation per technology in 2030 (baseline) is estimated by multiplying the technology share (%) by the estimated TEG range (GWh/year).

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geo-thermal	Biomass
Min (GWh/year)	22,804	15,203	63,851	4,561	15,203	18,243	9,122	3,041	0
Max (GWh/year)	30,418	20,279	85,170	6,084	20,279	24,334	12,167	4,056	0

Step 4: Calculate emissions levels based on technology-specific emission factors

To estimate the absolute emissions from the baseline scenario emission trajectory, we apply emission factors (EF) per technology to the estimated total electricity generation per technology. We also consider intensity improvements for these factors.

The emission factors per technology are assumed based on Table 6.7:

Technology	Coal	Oil	Gas
EF (tCO ₂ /MWh)	0.97	0.88	0.45

We can assume that, as a result of plant retrofit and additional capacity of power plants with better technology, these emission factors will improve by 1% for coal and by 8% for gas, leading to the following emission factors:

Technology	Coal	Oil	Gas	Total
Min (MtCO ₂ /year)	0.97	0.88	0.45	61.7
Max (MtCO ₂ /year)	29.2	17.8	35.3	82.3

Thus, the emissions levels from the baseline scenario emissions trajectory in 2030 are between 61.7 MtCO₂/year and 82.3 MtCO₂/year.

2. Estimate policy scenario emissions trajectory

We now take into account the implementation of RE policies.

The country has decided to focus on its solar potential to transition to a low-carbon power sector by 2030. To this end, an uncapped feed-in tariff policy for solar power has been implemented to promote uptake of solar power. In a first step, users estimate the technical potential for the assessment period of the policy as 1,200 MW (total RE potential, of which 800 MW is solar power). Assessment of the policy design characteristics therefore reduces this potential to 800 MW (the solar portion). Financial factors and the barrier analysis further reduce the policy's impact to 237–314 MW (for details see Table 5.4).

This translates to generation of 375–497 GWh/year in 2030, assuming annual average operation of 330 days per year at an average annual capacity factor of 20% for solar for the country. We estimate the specific yield for solar PV in terms of the capacity factor as:

Specific yield_{solar} PV = annual capacity factor × annual average operation

Specific yield_{solar} PV = 0.2 × 330 days/year × 24 h/day = 1,584 MWh/year/MW

We can then estimate the range of electricity generation potential (EG) from introducing the feed-in tariff for solar PV policy as:

EG_{min2030} = 237 MW × 1,584 MWh/year/MW = 375 GWh/year

EG_{max2030} = 314 MW × 1,584 MWh/year/MW = 497 GWh/year

As explained in Section 6.3.2 (step 3) we then need to re-examine the future electricity mix by taking into account factors such as the interaction of other policies, the country's electricity system type, and changes needed for the system to accommodate higher shares of VRE (see Table 6.6). After examination of these parameters in the country, we then assume that the solar PV generation originated from the feed-in tariff will replace coal generation.

Implementation of the solar PV feed-in tariff policy would increase VRE share to 20% in 2030, meaning that flexibility in the system would become very important. The country:

- Has an electricity system that is interconnected to neighboring countries' electricity systems
- Has implemented policies for energy demand reduction (e.g. energy efficiency)

Therefore, other than additional transmission and distribution infrastructure, the country's system can accommodate the VRE addition without the need for further changes.

Thus the final generation per technology in 2030:

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geo-thermal	Biomass
Min (GWh/year)	22,429	15,203	63,851	4,561	15,203	18,243	9,122	3,041	0
Max (GWh/year)	29,921	20,279	85,170	6,084	20,279	24,334	12,167	4,056	0

The next step is to estimate the emissions levels for the policy scenario emissions trajectory.

Similar to step 4 above, users can estimate the absolute emissions from the policy scenario emissions trajectory by applying emission factors per technology to the estimated total electricity generation per technology, while considering intensity improvements for these factors. Using the same assumptions as before for emission factors per technology and improvements in technologies over time, the absolute emissions from electricity generation are estimated as the sum of emissions from all technologies.

Technology	Coal	Oil	Gas	Total
Min (MtCO ₂ /year)	21.5	0.88	0.45	61.7
Max (MtCO ₂ /year)	13.4	17.8	35.3	81.8

Thus, the emissions levels from the policy scenario emissions trajectory are **61.3–81.8 MtCO₂/year**.

3. Estimate GHG reductions from RE policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory

Finally, the GHG reductions in 2030 from the RE policy (EmRed) are estimated by subtracting the estimated emissions in the policy scenario from the estimated emissions in the baseline scenario:

$$\text{EmRed}^{2030\text{min}} = 61.7 \text{ MtCO}_2/\text{year} - 61.3 \text{ MtCO}_2/\text{year} = 0.4 \text{ MtCO}_2/\text{year}$$

$$\text{EmRed}^{2030\text{max}} = 82.3 \text{ MtCO}_2/\text{year} - 81.8 \text{ MtCO}_2/\text{year} = 0.5 \text{ MtCO}_2/\text{year}$$

0.4–0.5 MtCO₂/year emission reduction

6.4.2. Calculate avoided GHG emissions

The avoided GHG emissions achieved by the policy are calculated by multiplying the GEF with estimated RE addition (estimated in chapter 5). This is the GHG impact of the policy. Table 6.9 provides a list of resources that can be used to estimate emission factors based on the combined margin approach.

Where the policy involves hydro or biomass power plants, additional emissions may have to be subtracted to take account of CH₄ emissions associated with reservoirs and emissions associated with growing crops, respectively.

In the case of high-VRE systems (in IEA phase 3 and above – see table 6.2), some of the RE addition may get curtailed (wasted), if the grid is congested. Therefore, users should apply a curtailment adjustment factor (f_{curtail}) to the RE addition in case of battery storage policies.

The effective RE addition should be calculated as:

$$\text{Net RE addition} = \text{RE addition} * (1 - f_{\text{curtail}})$$

(Bahar et al., 2019).



Finally, when reporting the assessment results, users can refer to the [Assessment Reporting Template](#), available for download in the Templates section.

Table 6.9. Resources available for estimating emission factors based on the combined margin approach

Resources	Description	Source
Article 6.4 methodological tool, A6.4-AMT-007 (emissions from electricity generation and consumption)	1. Detailed guidance providing calculation methodology 2. Country users use country-level data to calculate grid emission factors 3. Developed by Article 6.4 Methodological Expert Panel (MEP) in collaboration with UNFCCC secretariat 4. The tool was officially approved by Article 6.4 Supervisory Body (SBM) at its 20th meeting in February 2026	UNFCCC (2026)

Resources	Description	Source
Institute for Global Environmental Strategies (IGES) List of Grid Emission Factors	5. Database of country-specific grid emission factors 6. Collated from information provided in project design documents 7. Developed by IGES and regularly updated	Louhisuo and Mahachi (2026)
International Financial Institutions (IFI) GHG Accounting for Grid Connected Renewable Energy Projects	8. Guidelines for RE projects	IFI Technical Working Group on Greenhouse Gas Accounting (2019)

6.4.3. Example of calculating GHG impacts using the grid emission factor method

An example of calculating GHG impacts for a tender policy using the GEF method is shown

in box 6.2. Generally, the methodology and steps would remain the same in case of other types of policy.

Box 6.2. Example of calculating GHG impacts for a tender policy

A hypothetical country generates 500,000 GWh/year of electricity. Its generation mix comprises 50 per cent coal (250,000 GWh/year), 40 per cent gas (200,000 GWh/year) and 10 per cent hydro (50,000 GWh/year).

A tender policy for RE is introduced that consists of three rounds of tenders with the following breakdown: 40 MW in 2021, 100 MW in 2022 and 500 MW in 2023 (total 640 MW).

The tender policy is expected to contribute to a national target of 1,000 MW of RE capacity by 2030.

The technical potential for the assessment period of the tender policy (640 MW) is reduced by 14 per cent after the assessment of its design characteristics. Thus, the tender policy is expected to lead to 550 MW of RE deployment by 2030. This is further reduced to 450 MW after the assessment of factors that affect financial feasibility.

A series of barriers are subsequently identified that further reduce the impact of the tender policy by 17–25 per cent. Thus, the RE addition of the tender policy is estimated to be 338–374 MW (42–47 per cent lower than the technical potential for the assessment period).

This estimate translates to a generation potential of 6,023–6,653 GWh of power between 2021 and 2029, assuming 24 hours per day and 330 days of annual operation

with a 25 per cent capacity factor (considered appropriate to the country context), while accounting for the yearly capacity addition.

This exercise highlights the limitations of the tender policy to achieve the RE target.

The Government wants to estimate the GHG emissions reductions associated with the RE addition and chooses to use the GEF approach.

The ministry of energy consults with regulatory commissions and utility companies to define the spatial boundary of the grid. It decides to include both utility companies and independent power producers in the spatial boundary of the grid. Power imports and exports are also included in the assessment. The OM and BM of the grid are calculated. Using a simple OM and BM, and typical weightings used under the Clean Development Mechanism for solar and wind (w_{OM} , w_{BM} = 0.75, 0.25), the combined margin emission factor (EF) is calculated using the equation

$$EF_{grid,CM,y} = EF_{grid,OM,y} \times w_{OM,y} + EF_{grid,BM,y} \times w_{BM,y}$$

$$EF_{grid,CM,y} = 0.475 \text{ tCO}_2\text{e/MWh}$$

The generation potential due to the RE addition (EG) is

$$\Sigma EG_y = 6,023 \text{ GWh to } 6,665 \text{ GWh}$$

The estimated GHG emissions reduction (EmRed) of the RE tender policy between 2021 and 2029 is

$$\begin{aligned} Em_{Red} &= EF_{grid,CM,y} \times \Sigma EG_y \\ &= 2,860,925 \text{ tCO}_2\text{e to } 3,160,175 \text{ tCO}_2\text{e} \\ &= 2.86 \text{ MtCO}_2\text{e to } 3.16 \text{ MtCO}_2\text{e} \end{aligned}$$

Chapter 7:

Estimating GHG impacts of the policy ex-post

7.1 Introduction to estimating GHG impacts ex-post | 7.2 Estimate or update baseline emissions (if relevant) | 7.3 Estimate achieved renewable energy addition | 7.4 Estimate GHG impacts

Ex-post impact assessment evaluates the actual GHG impacts of a policy based on observed data during or after its implementation. Unlike ex-ante assessments, which rely on projected RE deployment, ex-post assessments use observed data to estimate achieved RE addition and resulting emissions reductions. Users conducting only ex-ante assessments may skip this chapter.



It is a key recommendation to:

- Estimate the RE addition achieved using monitored data for the parameters outlined in the monitoring plan.
- Estimate the GHG impacts of the policy over the entire assessment period for each GHG source within the defined assessment boundary.

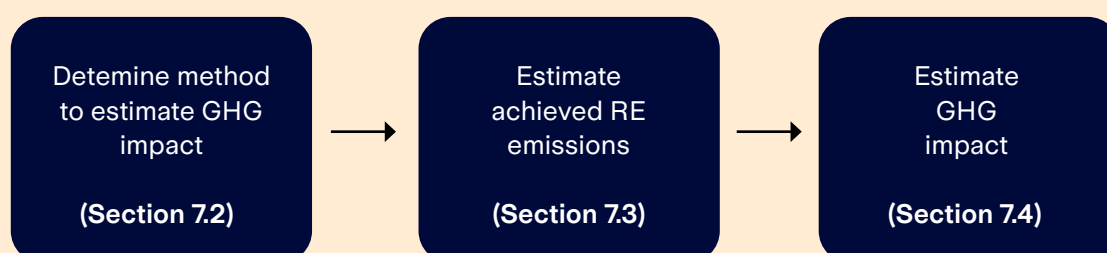
7.1. Introduction to estimating GHG impacts ex-post

This section focuses on estimating the GHG impacts of the policy ex-post while ensuring the desired level of accuracy for the assessment.

Ex-post GHG impact estimation serves three main objectives, each requiring a different assessment approach:

- **Objective 1 – Compare with policy targets:** Users can compare achieved RE additions with policy caps, national RE targets or GHG emissions levels with sectoral targets. This approach does not require a baseline scenario.
- **Objective 2 – Compare with a baseline scenario:** Users may want to assess what would have happened without the policy. This requires developing a baseline scenario, in which the same amount of electricity is assumed to be generated as in the policy scenario, but from business-

Figure 7.1. Overview of steps in this chapter



as-usual (non-RE) sources. All other conditions, such as economic trends, remain the same as in the policy scenario. This baseline is used to estimate GHG emissions levels (or trajectory) or GHG emissions reductions. To achieve this objective, users should follow the steps in sections 7.2, 7.3 and 7.4.

- **Objective 3 – Compare actual results (RE addition or avoided GHG emissions) with the ex-ante assessment:** Users can compare the achieved RE additions or GHG reductions with those projected in the ex-ante assessment. This helps assess whether the policy is performing as anticipated. Two possible outcomes are:

- **The achieved RE addition exceeds the projections:** This may indicate that the policy is working well and that other supportive policies (e.g., combining a renewable portfolio standard with a FiT) are enhancing the impact.
- **The achieved RE addition is lower than projections:** This may indicate that the policy was less effective than expected or that other policies interfered and reduced the intended impact.

This type of comparison helps identify policy overlaps, avoid double-counting emissions reductions and check the accuracy of initial assumptions. It also improves the quality of future ex-ante assessments by learning from actual outcomes.

To achieve the third objective, users need to follow the steps in sections 7.3. and 7.4.

7.1.1. Selecting the right level of accuracy for estimating ex-post GHG impacts

When deciding how to estimate ex-post GHG impacts, users should consider their assessment goals, the level of accuracy needed, data availability and quality, the ease of using the method and the resources and capacity available.

- **Low accuracy:** This approach uses broad, aggregated data – such as national energy generation statistics from government

agencies – and general emission factors based on the main source of electricity in the country.

- **Medium accuracy:** This approach uses grouped data from electricity buyers or distribution companies and region-specific emission factors that reflect the most common generation sources in those areas.
- **High accuracy:** This method uses detailed, disaggregated meter data, including electricity imports and exports, and precise data on auxiliary electricity use.

The choice of approach should balance the need for precision with practicality, based on the available data and resources. Users should note that to align with international reporting, they need to define 'levels of accuracy' as tiers, namely tiers 1 (default factors), 2 (country-specific) and 3 (plant-specific/model-based). This ensures compatibility with the Paris Agreement's ETF.

An example of ex-post estimation of the GHG impacts of an RE policy is given in box 7.1.

7.2. Estimate or update baseline emissions (if relevant)

To calculate the GHG emissions reductions from a policy, users must first estimate the baseline emissions. These baseline emissions should be updated each time an ex-post assessment is conducted.

- If using the emissions trajectory method, users should update the baseline emissions by following the steps outlined in section 6.1.
- If using the GEF method, this step can be skipped, as emissions reductions are estimated based on the RE addition and the updated GEF (see section 7.4).
- When updating baseline emissions, users should account for changes in grid infrastructure that may have occurred during the assessment period, such as new transmission lines that reduce the baseline level of curtailment independent of the policy being assessed.

Box 7.1. Example: Ex-post estimation of the GHG impacts of a RE policy**Policy description**

A country introduced a FiT for solar PV in 2018 to promote grid-connected renewable electricity generation. The policy aimed to install 1,000 MW of solar PV by 2022.

Observed policy outcome (ex-post)

By the end of 2022, 800 MW of solar PV had been installed under the FiT scheme, generating 1,400 GWh of electricity per year.

Baseline (counterfactual)

In the absence of the policy, this electricity would have been supplied by the existing grid mix. Based on historical dispatch data, the GEF for the period is estimated at 700 tCO₂/GWh.

GHG impact estimation

Annual GHG emission reductions attributable to the policy are calculated as:

GHG emission reductions = RE generation (GWh) × GEF (tCO₂/GWh)

= 1,400 GWh × 700 tCO₂/GWh = 0.980 MtCO₂

Interpretation

The ex-post assessment shows that the solar FiT policy resulted in 0.98 MtCO₂ of annual emissions reductions. Comparing this outcome with the original 1,000 MW policy target (of which only 800 MW was achieved) allows policymakers to assess the effectiveness of the policy, identify implementation gaps (such as grid connection delays or financing hurdles) and inform potential design improvements for future auction or tariff rounds.

7.3. Estimate achieved renewable energy addition

It is strongly recommended that the achieved RE addition is estimated using monitored data for the parameters outlined in the monitoring plan. This can be done in terms of RE capacity addition or additional RE electricity generation. The two key parameters to track are:

- Installed RE capacity
- Net electricity supplied to the grid from RE sources.

For policies involving energy storage, additional monitored parameters include (IEA, 2019):

- **Actual round-trip efficiency:** Measured ratio of energy discharged versus energy charged.

- **Storage cycle count:** To verify degradation rates and remaining useful life.
- **Avoided curtailment (GWh or MWh):** Volume of RE generation that was dispatched specifically due to the presence of storage. RE curtailment is therefore an important parameter to be monitored for these calculations.

If monitored data are unavailable or limited, users should estimate the RE addition using the best available data. See section 7.1.1 for guidance on selecting an appropriate approach based on the desired level of accuracy.

7.4. Estimate GHG impacts

Translate the achieved RE addition into GHG impacts using the method described

in chapter 6.2, based on monitored data from the ex-post policy scenario rather than projections. Chapter 7 on monitoring in the [Introductory Guide](#) lists all relevant indicators and parameters needed for this step.

It is strongly recommended that the GHG impacts of the policy are estimated over the entire assessment period for each GHG source within the defined assessment boundary.

- If using the emissions trajectory method: calculate GHG impacts by subtracting the baseline emissions (see section 7.2) from the actual emissions in the ex-post policy scenario for each source category.
- If using the GEF method: calculate GHG impacts by multiplying the baseline (counterfactual) GEF (calculated for the ex-post assessment) by the achieved net RE addition (in GWh), which, for battery storage policies, must account for any actual curtailment or storage round-trip losses recorded during the monitoring period.

Note: For net metering, the achieved RE addition should be adjusted upward to account for avoided T&D losses. This ensures that the calculation reflects the total amount of grid generation displaced (IEA, 2024).



Finally, when reporting the assessment results, users can refer to the Assessment Reporting Template, available for download in the [Templates section](#).

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Appendices

Appendix A: Information to describe policy

Table 4.A1. Checklist of recommended information to describe the policy being assessed

Information	Description	Example
Title of the policy or action	Policy name	FiT without cap
Type of instrument	The type of policy, such as those presented in Table 3.B1	FiT policy
Description of specific interventions	The specific intervention(s) carried out as part of the policy, such as the technologies, processes or practices implemented	Policy characteristics: ▪ Tariff differentiation – higher tariffs for small projects and lower tariffs for large-scale projects (set to give rates of return of 5–8 per cent) ▪ Eligibility – the only technology eligible under the FiT is solar PV ▪ Utility role – government-owned single buyer with guaranteed purchase up to the annual production quota ▪ Payment structure – premium price policies ▪ Contract and payment duration – premium is offered over a project's entire lifetime ▪ Forecasting – no forecasting requirements ▪ Grid access – grid priority for renewable energies ▪ Policy adjustments – only inflation adjustments over lifetime of FiT
Status of policy	Whether the policy is planned, adopted or implemented	Implemented

Information	Description	Example
Date of implementation	The date the policy comes into effect (not the date that any supporting legislation is enacted). In some cases, particularly for infrastructure policies such as RE support schemes, there may be a time lag between the implementation of the policy and the occurrence of GHG emission effects. This delay reflects the time required for project development, financing, construction and commissioning. Such timing considerations should be reflected in the estimation of policy impacts.	1 July 2016
Date of completion (if relevant)	If relevant, the date the policy ceases, such as the date a tax is no longer levied or the end date of an incentive policy with a limited duration (not the date that the policy no longer has an impact)	No end date has currently been set
Implementing entity or entities	The entity or entities that implement(s) the policy, including the role of various local, subnational, national, international or any other entities	Ministry of Energy/Energy Regulatory Commission
Objectives and intended impacts or benefits of the policy	The intended impact(s) or benefit(s) of the policy (e.g., the purpose stated in the legislation or regulation)	To increase deployment of solar PV and increase energy security
Policy level	The level of implementation, such as national, subnational, city, sector or project level	National

Information	Description	Example
Policy inputs	Resources that go into implementing a policy, such as the institutional mechanism established, the funding allocated to implement the policy – expenses related to training and education programmes, policy administration, expenses related to support for implementers, etc. (see chapter 6 of the Introductory Guide on the cost of policy implementation)	▪ Government budget allocated to finance FiT payments ▪ Establishment of an RE unit within the ministry of energy ▪ Recruitment and training of regulatory staff to administer the scheme ▪ Development of solar resource maps and grid integration studies
Policy activities	Administrative activities involved in implementing the policy undertaken by the authority or entity that implements the policy; for example, hiring of additional staff or offering grants to conduct training, issuing regulations, selection of implementers, follow-up activities (monitoring), etc.	▪ Issuing FiT regulations and tariff schedules ▪ Reviewing and approving solar PV project applications ▪ Signing PPAs with project developers ▪ Monitoring electricity generation and compliance with policy requirements
Geographic coverage	The jurisdiction or geographic area where the policy is implemented or enforced, which may be more limited than all the jurisdictions where the policy has an impact	Small, Least Developed Country
Sectors affected	The sector(s) or subsector(s) that are affected	Energy supply, grid-connected solar PV
GHGs affected	The GHGs the policy aims to control, which may be more limited than the set of GHGs that the policy affects	Carbon dioxide

Information	Description	Example
Costs	Information on costs may also be provided, including estimated or actual costs of implementing the policy, where available	- Government spending to cover FiT premium payments - Administrative costs for running the regulatory unit and managing applications - Capacity-building expenses for training staff - Costs for technical studies (e.g., resource mapping and grid studies) - Monitoring and compliance costs for verifying generation and ensuring contract adherence - Developer transaction costs for permits, documentation and PPA negotiations under the FiT scheme
Other related policies or actions	Other policies or actions that may interact with the policy assessed	Fossil fuel subsidies, tender policies, tax incentive policies

Table 4.A2. Checklist of additional information that may be relevant to describe the policy being assessed

Information	Description	Example
Intended level of mitigation to be achieved and/or target level of other indicators	Target level of key indicators, if relevant	National target: 15 per cent share of PV or RE in electricity mix 20 per cent sectoral emissions reduction below base-year Y Policy: - The policy does not have a separate target but instead is designed in an open-ended manner, i.e. is not bound by any targets or goals of RE addition that it is aiming to achieve.

Information	Description	Example
Title of establishing legislation, regulations or other founding documents	The name(s) of the legislation or regulations authorizing or establishing the policy (or other founding documents, if there is no legislative basis)	Energy policy act
Measurement, reporting and verification procedures	References to any measurement, reporting and verification procedures associated with implementing the policy	A coordinating body will be formed to ensure continuous monitoring and create a monitoring plan. The power producer establishes quality assurance and quality control measures to control and manage reading, recording, auditing and archiving all relevant data and documents. Monitoring data for net electricity generation at the plant level can be obtained from the periodic electricity meter records kept by the power producer and/or the electricity board or grid company. These can be cross-checked with invoices sent by power producers to the grid company.
Policy key performance indicators	Metrics that indicate the state or level of a policy's performance. For mitigation policies included in a country's NDC, the KPIs will be used for NDC implementation tracking and should meet the requirements set out in the modalities, procedures and guidelines (MPGs) for the transparency framework.	▪ Installed solar PV capacity (MW) ▪ Annual renewable electricity generation (MWh) ▪ Share of RE in electricity mix (percentage) ▪ Estimated GHG emissions reduced (tCO₂/year) ▪ Number of projects supported under the FiT ▪ Average tariff level and total payments disbursed ▪ Cost per tonne of CO₂ reduced

Information	Description	Example
Compliance and enforcement mechanisms	Compliance and enforcement procedures, such as reporting requirements to verify implementation and/or penalties for non-compliance, if applicable	Power producers are required to install certified meters and submit periodic electricity generation reports to the Energy Regulatory Commission. Generation data may be subject to verification and audit. In cases of misreporting or non-compliance, penalties may include repayment of excess payments, financial fines, suspension from the FiT scheme or termination of the PPA.
Reference to relevant documents	Information to allow practitioners and other interested parties to access any guidance documents related to the policy (e.g., through websites)	Renewable Energy Sources Act
Broader context or significance of the policy	The broader context for understanding the policy	The policy will contribute to the national target of a 15 per cent share of PV or RE in the electricity mix and a 20 per cent reduction in sectoral emissions below base-year 2005. The policy will reduce consumption of fossil fuels and contribute to energy security.
Outline of sustainable development impacts of the policy	Any anticipated sustainable development benefits other than GHG mitigation	The policy will lead to more construction jobs and greater energy security. Solar energy will also provide quick alternative power during severe climate changes that may occur (El Niño). It will lead to increased solar electricity generation in the country, contributing to energy security by displacing fossil fuel energy sources that require fuel imports.

Information	Description	Example
Outline of transformational change impacts of the policy	The extent to which the policy contributes to long-term structural shifts in systems, markets or behaviours beyond immediate GHG reductions	The policy supports long-term market development for solar PV by creating stable investment conditions, encouraging private sector participation and contributing to a gradual shift of the electricity system towards RE.
Key stakeholders	Key stakeholder groups affected by the policy	▪ Departments or ministries of energy ▪ Energy regulatory commissions ▪ Energy planning offices ▪ Power producers ▪ Investors ▪ Utilities ▪ Consumers ▪ Constituents affected at installation sites
Other relevant information	Any other relevant information such as policy co-benefits, interactions with other policies, barriers to implementation and/or trade-offs	The policy may interact with fossil fuel subsidies. Potential barriers include fiscal sustainability and grid integration challenges. It may increase investment and innovation in the RE sector.

Source: Adapted from Rich et al. (2014).

Appendix B: Criteria for policy selection and overview of key policy instruments

Appendix 3.B1: Criteria for selecting the policy types covered by the ICAT Renewable Energy Methodology

The previous version of the ICAT Renewable Energy Methodology covered three core policies – FiTs, auction policies and tax incentive policies – due to their widespread use and demonstrated effectiveness in supporting the deployment of RE. However, based on feedback received by ICAT from different key stakeholders, a need was identified to expand the scope of the guide to better reflect emerging trends, evolving market dynamics and diverse policy environments across countries.

To address this, the current update introduces two additional policy types. This decision reflects the growing adoption of new policy instruments in developing countries, feedback from stakeholders emphasizing the importance of policies that support market development, energy storage and the integration of VRE, and the need to ensure that the guide remains relevant, practical and applicable across a broad range of national contexts.

The two additional policies were selected from a shortlist of high-impact options that align with the overall objectives of the guide and have clear potential to contribute to increased RE deployment and associated GHG emission reductions. The selection process was guided by a set of general criteria to ensure transparency, relevance and consistency.

This appendix describes the criteria and process used to select the RE policy types covered by the ICAT Renewable Energy Methodology.

Policy selection approach

The selection of policy types was informed by a structured review process combining a comprehensive literature review with stakeholder consultations. The literature review

examined a wide range of RE policy instruments implemented across different country contexts and income levels. Stakeholder consultations provided insights into policy relevance, implementation experience, data availability and emerging trends.

Based on this initial stocktaking, a filtering and shortlisting process was applied to identify policy types that are suitable for inclusion in a methodological guide focused on the assessment of GHG impacts.

The objective of this process was to identify policy types that are methodologically assessable, widely relevant and practically useful, particularly for countries with limited data availability and technical capacity.

Policy selection criteria

Policy types were assessed against the following criteria:

1. **Prevalence of use**
Priority was given to policy types that are widely implemented across countries, particularly in developing country contexts, and which represent commonly used approaches to promoting renewable electricity generation.
2. **Direct linkage to renewable electricity deployment**
Policy types were required to have a clear and demonstrable cause-effect relationship with increased grid-connected renewable electricity generation, enabling the construction of a transparent causal chain.
3. **Feasibility of GHG impact estimation**
Consideration was given to whether the impacts of the policy type can be reasonably estimated ex-ante and/or ex-post using available data and established assessment approaches.
4. **Applicability across national contexts**
Policy types were selected based on their potential applicability across a wide

range of national circumstances, avoiding instruments whose impacts are highly context-specific or dependent on complex institutional or market conditions.

5. Insights from literature and stakeholder consultations

Findings from the literature review and stakeholder consultations were used to identify policy types considered particularly relevant, emerging or challenging from an assessment perspective, including those linked to technological and market developments.

6. Clarity and practicality of methodological scope

To ensure usability, the ICAT Renewable Energy Methodology focuses on a limited number of policy types for which clear, step-by-step guidance can be provided. Policy types with indirect, system-wide or highly aggregated impacts were not prioritized.

Outcome of the policy selection process

Applying these criteria resulted in the selection

of two additional RE policy types for which assessment methodologies are provided in the ICAT Renewable Energy Methodology. These are net metering policies and VRE integration with grid-battery storage policies. These policy types:

- Are commonly used to promote renewable electricity generation
- Allow for a consistent and transparent estimation of RE additions and associated GHG impacts
- Support a focused and practical methodological framework for users

Other RE-related policy instruments – such as carbon pricing mechanisms, emissions trading schemes, tradable RE certificates, regulatory reforms and capacity-building measures – were not selected for detailed methodological coverage. While such instruments can play an important role in supporting RE deployment, their impacts are either indirect, highly context-dependent or outside the primary focus of the ICAT Renewable Energy Methodology.

Table 3.B1. Overview of key policy instruments implemented in the energy supply sector in both developed and developing countries (2021)

No.	Policy	Number of countries using the policy in 2021	
		Developed countries	Developing countries
1	FIT and feed-in premium policies These policies guarantee RE producers a fixed price (FIT) or a premium above the market electricity price (feed-in premium) for electricity generated from renewable sources. They are designed to encourage investment in RE by ensuring stable and predictable revenue streams.	33	49
2	Reduction in sales, energy, value-added tax (VAT) or other taxes Governments reduce or exempt certain taxes on energy technologies, fuels or equipment to lower investment and operational costs. These incentives can apply to both renewable and conventional energy technologies, depending on policy design.	38	72

No.	Policy	Number of countries using the policy in 2021	
		Developed countries	Developing countries
3	Auctions and tenders Governments invite developers to bid competitively to supply electricity from RE projects. Contracts are typically awarded to projects offering the lowest price, helping reduce costs while expanding renewable generation capacity.	42	61
4	Net metering Net metering allows electricity consumers who generate their own renewable electricity (e.g., solar photovoltaics [PV]) to feed excess electricity into the grid and receive credits on their electricity bills. This policy encourages distributed RE generation.	29	41
5	Electric utility quota obligation/renewable portfolio standards (RPS) These regulations require utilities or electricity suppliers to ensure that a specified share of their electricity generation comes from RE sources. Compliance is often monitored through certificates or penalties for non-compliance.	17	16
6	Biofuel blend renewable transport obligation/mandate Governments mandate that a minimum percentage of biofuels must be blended with conventional transport fuels such as gasoline or diesel. This policy promotes the use of renewable fuels in the transport sector and reduces fossil fuel dependence.	35	27
7	Renewable heat obligation/mandate, heat FiT, fossil fuel ban for heating These policies promote renewable heating technologies such as solar thermal, biomass or heat pumps. Measures may include mandatory renewable heat shares, financial incentives for renewable heat generation, or restrictions on fossil fuel-based heating systems.	16	9

No.	Policy	Number of countries using the policy in 2021	
		Developed countries	Developing countries
8	Tradable renewable energy certificates (TREC) TREC systems create market-based certificates representing electricity generated from renewable sources. Utilities or companies can buy and trade these certificates to meet RE obligations set by government policies.	26	8
9	Investment or production tax credits Tax credits reduce the tax burden for investors or producers of RE. Investment tax credits (ITCs) lower upfront capital costs, while production tax credits (PTCs) provide financial support based on the amount of electricity generated.	20	25
10	Energy production payment (production-based incentives) These incentives provide direct financial payments to RE producers based on the quantity of electricity generated. The aim is to improve project profitability and encourage RE deployment.	15	9
11	Public investment loans, grants, capital subsidies or rebates Governments provide financial support such as low-interest loans, grants or subsidies to reduce the capital costs of RE projects. These mechanisms help overcome financial barriers and stimulate investment in renewable infrastructure.	41	59
12	Other financial incentives (interest subsidies) Governments reduce interest rates or provide financial guarantees for energy investments, lowering the cost of borrowing. These incentives can support RE, but may also apply to broader energy or infrastructure projects.	Several	Several

No.	Policy	Number of countries using the policy in 2021	
		Developed countries	Developing countries
13	VRE integration with grid-battery storage policies These policies support technologies such as battery storage and grid upgrades that help integrate variable RE sources like solar and wind into the electricity system. They enhance grid flexibility and reliability as renewable penetration increases.	Several	Several pursuing battery storage system, mostly at pilot stage
14	Building standards and green building policies Green building policies establish standards or regulations to improve building energy efficiency and encourage sustainable construction practices. They may indirectly promote RE use through requirements for on-site renewable systems or energy performance standards.	Several (International Finance Corporation, 2020)	Several
15	Green bonds and climate finance Green bonds and climate finance mechanisms mobilize capital specifically for environmentally sustainable projects, including RE, energy efficiency and low-carbon infrastructure. They enable Governments, financial institutions and corporations to raise funds dedicated to climate mitigation and adaptation initiatives.	30–40 (2024) (International Monetary Fund, 2025)	30–40 (2024)
16	Carbon pricing mechanisms and emissions trading Carbon pricing policies place a financial cost on GHG emissions through carbon taxes or emissions trading systems. By increasing the cost of fossil fuel use, they indirectly encourage investment in low-carbon and RE technologies.	About 10 (in initial stage) (World Bank Group, 2024)	Several
17	Grid infrastructure improvement policies These policies focus on upgrading transmission and distribution networks to accommodate increasing shares of renewable electricity. Measures include grid modernization, smart grid deployment, expansion of transmission lines, and improved system flexibility to support variable RE integration (Hevia-Koch et al., 2023; International Renewable Energy Agency [IRENA], 2024a; Reidenbach, Bertoli and Kieffer, 2024).	Several	Several

No.	Policy	Number of countries using the policy in 2021	
		Developed countries	Developing countries
18	Green power purchase agreement (PPA) Green PPAs are long-term contracts in which corporations or utilities agree to purchase electricity directly from RE producers at a predetermined price. These agreements provide financial certainty for developers and accelerate private sector investment in RE projects.	Several	Several

Source: REN21 (2021)

Appendix C: Resources and examples to estimate RE addition

Appendix 5.C1: Overview of the LCOE method for renewable energy sources

The LCOE is the unique cost of an energy project, representing the present value of the costs over the lifetime of the project. The LCOE is defined as the price of electricity “required for an energy project where revenues would equal costs, including a return on the capital invested equal to the discount rate” (Ilas et al., 2018). An electricity price above this value would result in a greater economic return on the investment, while an electricity price below the LCOE would result in a lower economic return.

The generic formulas to calculate the LCOE of RE technologies are shown in equations C1 and C2 (Ilas et al., 2018), and the variables and parameters are listed in table C1 below:

Equation C.1.

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+d)^t}}{\sum_{t=1}^n \frac{E_t}{(1+d)^t}}$$

Equation C.2.

$$E_t = P_t \times 8760 \times CF_t$$

Given the capital-intensive nature of most RE technologies and the fact that fuel costs are low (zero for many RE technologies), the WACC, also referred to as the discount rate d , used to evaluate the RE project has a critical impact on the LCOE (Ilas et al., 2018). The LCOE of RE technologies varies

Table 5.C1. Variables and parameters for calculating the LCOE of RE technologies

Input parameter	Description	Unit
LCOE	Average lifetime levelized cost of electricity generation	US\$/kWh
I_t	Investment expenditures in year t	US\$
M_t	Operational and maintenance costs in year t	US\$
F_t	Fuel costs in year t	US\$
E_t	Electricity generation in year t	kWh
d	Discount rate (or weighted average cost of capital)	%
n	Economic lifetime of the system	Years
P_t	Power generation capacity of the system	kW
CF_t	Capacity factor in year t	Dimensionless

by RE technology, country and project size. It is determined taking into account the RE resource at a project site, capital and operating costs, and the performance/ efficiency of the RE technology. When a policy has a wide geographical coverage with different physical conditions for RE generation (e.g., wind power), it is recommended that LCOEs are calculated specifically for each region or location. IRENA provides input values for LCOE (US\$/kWh), total investment costs (US\$/kW) and capacity factors for different RE technologies across different regions (Ilas et al., 2018).

Modified LCOE with battery storage

LCOE = Same as LCOE above, but add R_t in the investment (thus numerator: $I_t + M_t + F_t + R_t$) where

R_t : Battery replacement costs over the lifetime of the plant

I_t : Investment in plant

M_t : Operation and maintenance costs, including for battery

F_t : Fuel costs, for VRE, if any, and for battery charging: net energy delivered (VRE + battery discharge – losses)

Other parameters remain the same.

Table 5.C2. RE policy examples

This appendix provides examples of RE policies from a number of countries, along with case studies of RE policies from the literature. This information can be used to support the benchmarking exercise users can undertake after calculating RE addition.

Example feed-in-tariff policies

Country	Main design characteristics	Main barriers and challenges	Impact achieved
South-East Asia FiTs from five South-East Asian economies (Indonesia, Malaysia, Philippines, Thailand and Viet Nam) covering biomass, hydropower, solar and wind (Azhgaliyeva, 2023).	FiTs are analysed as a core policy instrument intended to promote RE by providing predictable revenue streams and risk-mitigating incentives that make projects more financially attractive to investors	The influence of FiTs and other energy policies on investment is context-dependent and varies by country, financing type and firm characteristics, suggesting that a one-size-fits-all policy may not mobilize private capital effectively everywhere. While FiTs can reduce investor risk, gaps in complementary measures (e.g., tax incentives or R&D support) and broader macroeconomic conditions complicate the investment landscape, potentially limiting how much FiTs alone can stimulate investment. RE investors face uncertainty around energy prices, regulatory stability and technology costs, all of which can influence investment decisions and complicate the interpretation of FiT impacts, especially where policy consistency is weak.	FiTs have a measurable influence on attracting private investment in RE assets in South-East Asia, particularly when they reduce revenue uncertainty and improve expected returns for firms. The evidence suggests that FiTs and related policy instruments can differentially mobilize distinct sources of private finance (e.g., asset finance versus venture capital), indicating more nuanced investment pathways rather than uniform effects across all financing channels.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Mozambique Mozambique approved a Renewable Energy Feed-in Tariff (REFiT) regulation (Decree no. 58/2014) (Come Zebra and Mahumane, 2019) to promote small/medium renewable projects (Come Zebra et al., 2021).	The REFiT regulation in Mozambique is designed to promote renewable energy deployment (hydro, solar, wind and biomass) by guaranteeing preferential pricing to independent power producers to encourage investment, in the context of achieving the country's NDC climate targets.	Weak coordination between institutions, insufficient technical capacity, lack of consistent data-collection and sharing mechanisms, and limited financial resources are major obstacles to establishing effective monitoring reporting and verification systems. FiTs and capacity caps set out in the policy may no longer align with declining renewable technology costs and evolving markets, suggesting a need for tariff revisions and policy redesign to enhance effectiveness.	The analysis shows that full implementation of the FiT policy could contribute to reducing up to 2.54 MtCO ₂ eq by 2030, representing about 4.3 per cent of the electricity sector's NDC target, significantly larger than the limited scenario and indicating a pathway to raise ambition if fully deployed.
Viet Nam On 10 April 2025, the Ministry of Industry and Trade issued Decision 988/QD-BCT, updating FiT rates for solar power projects in Viet Nam. These tariffs, which came into effect under Circular 09/2025/TT-BCT issued on 1 February 2025, will apply throughout 2025 (Do et al., 2021).	Viet Nam first introduced FiTs to stimulate investment in solar and wind energy, offering stable, long-term returns for private investors. In 2023, this mechanism was revised to cover a wide array of renewable projects. FiTs are now calculated within a pricing corridor ranging from VND 0/kWh to a government-determined maximum, updated annually. Viet Nam Electricity (EVN), in coordination with the Electricity Regulatory Authority of Viet Nam (ERAV), is tasked with determining the yearly rates based on updated technical, economic and participation data from developers. For example, FiTs for ground-mounted solar projects without storage can range from US\$0.039 to 0.053/kWh (based on the region in which the project is being developed).	The Government has largely phased out these high FiTs from the previous mechanism, mainly because many projects were embroiled in disputes regarding the validity of their commercial operation date status and eligibility for these rates. New projects are largely expected to operate under competitive bidding, reflecting a shift away from high, uniform incentives.	Solar and wind electricity generation in Viet Nam rose from 4.7 TWh in 2019 to 9.5 TWh in 2020.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Sri Lanka In 2024, Sri Lanka updated its FiTs for solar projects, transitioning from earlier, higher rates to lower, “cost-reflective” tariffs. These updates were generally governed under the Sri Lanka Electricity Act, No. 36 of 2024, and regulatory decisions (Sri Lanka, Public Utilities Commission, 2023; Economynext, 2025).	The state-run Ceylon Electricity Board in Sri Lanka announced FiTs for RE for standardized power purchase agreements below 10 MW, without competitive tendering, effective from June 2025, reducing them from earlier levels. ▪ Mini hydro will be given LKR 25.74, down from LKR 30.53 /kWh. ▪ Wind will get LKR 23.83, down from LKR 29.86. ▪ Ground-mounted solar will get LKR 17.82, down from LKR 25.48. ▪ Floating solar will get LKR 24.33. ▪ Municipal biomass will get LKR 44.04. ▪ The FiTs are on a 20-year PPA. ▪ Biomass will get LKR 31.25 under a scalable rate, down from LKR 52.77.	Subsequent tariff cuts in 2025 (up to ~30 per cent reductions) have discouraged investment confidence and struggled to balance investor returns with consumer affordability. Additionally, lack of battery energy storage integration has led to curtailment of solar generation, reducing effective use.	Rooftop solar capacity supported by FiTs accounts for roughly 1,700 MW of installed generation, far exceeding ground-mounted capacity developed under competitive bidding.
Kenya The 2021 update to the FiT policy in Kenya, often guided by the Energy Act No. 1 of 2019, shifted focus away from large-scale solar and wind projects towards smaller projects (IEA, 2025d).	The FiT policy in Kenya has been periodically revised, with the most recent formal update in 2021 shifting focus towards smaller projects for biogas, biomass and small hydro (under 20 MW). The tariff for small-scale solar can range from US\$0.10 to US\$0.20 / kWh (20-year time period).	The 2021 FiT policy explicitly covers biomass, biogas and small hydro ≤20 MW, but solar and wind above that threshold are handled via auctions. This segmentation can limit FiT-driven deployment of some technologies in the higher capacity range. The move towards auctions for large projects can create uncertainty for developers who were originally targeting FiT-based revenue models. Ongoing policy reform may create transitional risk between support mechanisms.	Contributed to expanding renewable market maturity and smaller- capacity additions.

Example auctions and tender policies

Country	Main design characteristics	Main barriers and challenges	Impact achieved
South-East Asia Cambodia, Indonesia, Malaysia, Myanmar, Philippines and Thailand (Guadarrama et al., 2022)	RE auctions in South-East Asia vary substantially between countries, reflecting differing starting points, resource potential and policy objectives. Designing qualification and bid rules that both exclude underperforming bidders and attract enough competitive participation is a key characteristic. Some jurisdictions integrate local content requirements or criteria to support domestic industry development and job creation, even if this may raise short-term costs in exchange for broader socioeconomic benefits.	The range of maturity levels and policy environments across Association of Southeast Asian Nations (ASEAN) countries means there is no single 'one-size-fits-all' auction design; adapting global best practices to local conditions remains a challenge. Effective auction outcomes depend on accessible information about auction rules and procedures, and gaps in transparency can deter participation or lead to suboptimal results.	RE auctions have become an increasingly popular instrument in South-East Asia for procuring renewables, underlining their utility in driving deployment compared with other mechanisms. Where auctions are well designed, they can enhance competition and contribute to cost reductions for renewables relative to older support schemes.
Colombia Renewable Energy Law (Law 1715 of 2014) and its update, Law 2099 of 2021 (Guadarrama et al., 2021).	RE auctions in Colombia were designed to address the limitations of existing market mechanisms and attract non-hydro RE investment at scale. After an initial auction that assigned bids but awarded no contracts, the second auction refined key design elements (demand, qualification, winner selection and risk allocation), resulting in successful contract awards. Auctions used long-term PPAs that provide stable revenues and help reveal real competitive prices for wind and solar energy.	The first auction did not result in the award of contracts, pointing to early challenges in designing mechanisms that could successfully mobilize investment. Although improved in later rounds, managing the balance between sufficiently rigorous standards and not discouraging participation remains a design and administrative challenge. Stand-alone auctions lack long-term scheduling, which can limit investor confidence and market development potential compared with systematic, multi-round auction schemes.	The second auction successfully secured around 1.3 GW of new wind and solar capacity, scheduled to become operational by 2022, marking a tangible expansion of the RE pipeline. Weighted average auction prices for solar (approx. US\$28.40/MWh) and wind (approx. US\$27.70/MWh) were significantly lower than global auction averages, reflecting strong resource potential and investor interest.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Japan Renewable Energy Act (2012, amended 2022), Marine Renewable Energy Act (2019, amended 2025) (Guadarrama, Kachirayil and Abou Ali, 2022).	RE auctions in Japan have primarily focused on price discovery, with relatively simple design rules aimed at competitive bidding under long-term PPAs. This builds on reforms to the Feed-in Tariff Act to introduce auctions as a complement to previous support schemes. By late 2020, Japan had conducted several auctions – five for solar PV and two for biomass – and initiated a zone-specific offshore wind auction, reflecting an incremental auction roll-out. Auctions are positioned alongside other mechanisms such as planned feed-in premium (FiP) schemes to support renewable uptake beyond pure price competition.	Despite planning to auction large volumes of solar PV capacity, only a fraction of that capacity has been awarded through auctions, indicating challenges in sustaining bidder participation. Auction prices in Japan remain higher than global averages, influenced by relatively high local installation and equipment costs as well as grid connection and land availability constraints.	Auction results showed notable price reductions over successive rounds, highlighting the ability of the mechanism to reveal competitive pricing even if absolute prices remain elevated. While capacity awarded through solar and biomass auctions has been relatively modest compared with targets, the process has contributed to the diversification of the energy mix in Japan, away from nuclear and fossil fuels.
Denmark Danish energy policy is shaped by periodic Energy Agreements (e.g., 2018 and 2020) and the Climate Act (2019), which legally binds Denmark to achieve carbon neutrality by 2050 (Garzón González and Kitzing, 2019).	Denmark has evolved from technology-specific auctions (e.g., individual offshore wind tenders) towards multi-technology auctions that let onshore wind, solar PV and hybrid projects compete in the same tender rounds. Auctions typically use pay-as-bid rules with fixed or sliding premiums (e.g., sliding premium with two-sided Contracts-for-Difference), financed through public service obligations.	There have been few winning bidders across rounds, and some local or citizen-based consortia have struggled to pre-qualify, indicating participation barriers for smaller players. Earlier offshore wind auctions featured complex elements (e.g., penalties, timing and support design) that influenced participation and bid pricing; lessons from those rounds emphasized the importance of investor-oriented design features.	Across recent auction rounds, support premiums (and thus the public cost per unit of clean energy) have fallen substantially, reflecting strong competitive price discovery and reduced subsidy needs over time. Multi-technology auctions enabled competitive interaction between solar and wind bids, helping inform cost-efficient support levels and diversify renewable capacity additions.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Sub-Saharan Africa (Eberhard, Kruger and Volk, 2018) Uganda: GET FiT programme South Africa: The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (Eberhard, Kruger and Volk, 2018) Zambia (scaling solar programme) (Eberhard, Kruger and Volk, 2018).	Analysis of RE auction programmes in Uganda, South Africa and Zambia, emphasizing the use of auctions to determine competitive pricing for wind and solar power in emerging market contexts. Auctions are positioned as an alternative to FiTs, offering transparent price discovery.	Auction prices reflect only part of the investment context. Other factors, such as access to finance, macroeconomic conditions and risk allocation among stakeholders influence outcomes, making simple price comparisons misleading. Too much government intervention in site selection and process design can increase costs and investor risk, as seen in some sub-Saharan auction schemes, indicating the need for balanced roles and clarity in responsibilities.	In several cases, notably the South African programme, auction outcomes led to prices for wind and solar that were lower than the average cost of electricity from the national utility and less than new coal generation, demonstrating the cost competitiveness of renewables in the region. Several countries in sub-Saharan Africa have implemented auctions and many others are developing programmes, indicating broad regional uptake of the mechanism as a procurement tool.

Example tax incentive policies

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Argentina (Cabr� et al., 2015a) Law 25019, Art. 3 enacted September 1998 for solar and wind (Argentina, 1998); Law 26190, Art. 9 enacted December 2006 (Argentina, 2006), including Decree 562/2009 (including wind, solar, geothermal, tidal, hydro, biomass, landfill gas, purification gas and biogas); Law 27191, Arts. 3 and 4 enacted October 2015 (amendment to Law 26190) (Argentina, 2015) Law 26334 01/2008 for biofuels	Available technologies are wind, solar, geothermal, tidal, small hydro, biomass, landfill gas, purification gas and biogas (BloombergNEF, 2025). At national level: - Accelerated income tax depreciation - VAT rebate: 15-year VAT deferral from capital investments in wind and solar equipment (from enactment of Law 25019) At provincial/local level (Cabr� et al. 2015a; KPMG, 2015): - Real estate tax exemption - Stamp duty exemption - Turnover tax exemption/ deferral - Tax stability	Market barriers: - Subsidies for consumption of fossil fuels. - Tax breaks for companies investing in oil and gas - Tax incentives to promote exploration (Pickard, 2015) - Availability of substantial amounts of natural gas and hydropower makes other sources uncompetitive (Haselip et al., 2011) - Lack of support from financial institutions Institutional and administrative barriers: Public investment in fossil fuel power stations (Pickard, 2015).	No ex-post impact study available.
Colombia Law 1715 (Colombia, 2014) and its Decree 2143 (Colombia, 2015) published November 2015 and effective February 2016; Law 1716 (2014) Arts. 11 to 14; Energy Transition Law (Law 2099) passed in 2021, which now covers hydrogen	Explicit fiscal incentives described in Laws 1716 and 1715 (Decree 2143): 50 per cent tax break on investment over 5 years - VAT exemption for equipment and machinery (local or foreign) associated with the project - Accelerated depreciation of assets - Exemption from import duty - Tax exemptions for biofuels: some biofuel plants are labelled tax-free zones (Cabr� et al., 2015b)	Market barriers: - Subsidies for fossil fuels, although reduced over time, are still present (Colombia, Unidad de Planeaci�n Minero-Energ�tica [UPME], 2015) - Oligopolies for conventional energy production (Colombia, UPME, 2015) - Slightly higher investment costs for renewable technology than for conventional Techno-economic barrier: Lack of technical requirements to connect	Law 1715 and other associated laws have led to the installation of solar and wind capacity of around 9 per cent of the total electricity matrix by 2024.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
		and operate wind parks and small solar PV projects (Colombia, UPME, 2015) Infrastructure barrier: Lack of transmission lines in areas with the greatest potential for wind energy generation Public acceptance and environmental barrier: Competition with historical heritage interests in the area Lack of awareness and skilled personnel: Insufficient skilled workers, and lack of training and education	
Madagascar Under the Madagascar Tax Code, RE investments can benefit from corporate income tax reductions, VAT exemption and accelerated depreciation (Price waterhouse Coopers, 2025a).	Madagascar offers significant corporate income tax reductions for RE investments, allowing companies to reduce their tax liability by 20 per cent of the invested amount, capped at 50 per cent of the total tax due. Additional incentives include accelerated depreciation (30 per cent) on equipment and potential VAT exemptions for solar/wind equipment.	Renewable capacity growth in Madagascar has remained modest because of broader economic and infrastructure constraints. Historically, the private sector has had limited participation due to regulatory uncertainty, slowing down new projects.	While exact generation attributed to tax incentives alone is not reported, general renewable capacity has grown from negligible to several tens of MW, showing movement towards diversification.
Pakistan In May 2022, the Federal Government of Pakistan revised its proposal to impose an 18 per cent General Sales Tax (GST) on imported solar panels, reducing it to 10 per cent (Comfort Solar, 2025).	In the 2025–2026 budget, the Government initially proposed an 18 per cent GST on imported solar panels following a surge in imports. Following pushback from stakeholders and parliamentarians, the Government agreed to revise the proposal to a 10 per cent sales tax, rather than the initial 18 per cent. The removal applies to solar modules, directly lowering equipment costs for developers and consumers.	Currency grid integration challenges as well as fluctuations and import dependency still drive high costs for solar equipment, even with the removal of the GST.	Pakistan has rapidly expanded solar PV installations, particularly rooftop systems and utility projects. The growth in solar capacity also reflects net metering and auction policies beyond tax incentives.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
	The move aims to encourage local manufacturing while addressing the rapid growth in solar panel imports.		
South Africa In 2016, South Africa amended its Income Tax Act (section 12B) to offer accelerated depreciation allowances for RE machinery (Price water house Coopers, 2025b).	An accelerated depreciation allowance (50 per cent in the first year of use, 30 per cent in the second and 20 per cent in the third year) applies to the machinery and articles used in farming, production of biodiesel or bioethanol, and production of energy from certain renewable sources. This allowance has been temporarily expanded to allow taxpayers to claim a 125 per cent deduction in the first year for all RE projects. The expanded incentive will only be available for investments brought into use for the first time between 1 March 2023 and 28 February 2025. Solar PV systems ≤ 1 MW can be fully depreciated in the first year; larger systems and other renewable assets receive accelerated depreciation. This effectively reduces taxable income soon after investment.	Grid bottlenecks and network access issues have slowed deployment, especially outside auction programmes. Incentives are sometimes less visible compared with auction premium tariffs or direct grants.	

Example net metering policies

Country	Main design characteristics	Main barriers and challenges	Impact achieved
India Rajasthan net metering policy 2015 (Rajasthan Electricity Regulatory Commission, 2015).	Net metering policy implemented for rooftop PV installations Tariff rate of INR 7.5 per installed unit Cumulative installation limit of 30 per cent of a distribution transformer's capacity Rooftop plant size: 1kW to 1MW, cannot exceed 80 per cent of the sanctioned connected load	Limited capacity of individual distribution transformers (30 per cent of capacity) Restrictions on maximum rooftop plant size (80 per cent of sanctioned load) Regulatory and technical challenges in monitoring and managing distributed generation Awareness and adoption rate in rural areas	Encouraged adoption of solar rooftop PV in the state Contributed to RE generation and grid stability. Growth in private solar power generation. Enhanced grid integration of decentralized energy systems.
Morocco Law No. 58-15 introduced in 2016 (Morocco, 2016).	Net metering scheme for solar PV and onshore wind plants Applicable to power plants connected to the high-voltage grid Private generators can sell up to 20 per cent of their production to the grid	Limited to high-voltage grid connections, restricting small-scale producers Market uncertainties regarding PPAs Potential regulatory challenges and lack of incentives for smaller installations	
Brazil Through Normative Resolution no. 482/2012, the Brazilian Electricity Regulatory Agency (ANEEL) regulated net metering, known as the Electric Energy Compensation System (EECS) in the country (Hidalgo Leite, 2024).	Brazil established the regulatory framework for distributed generation in Brazil, enabling consumers to generate their own electricity from renewable sources and utilize a net metering system. It permits compensation for surplus energy fed into the grid, initially allowing credits for 36 months, later extended.	Moving from the previous to the current net metering regime reduces average returns for investors by about 5.77 per cent and a proposed alternative rule would reduce returns even more (about 12.81 per cent), indicating sensitivity to compensation design. Designing net metering policy that balances consumer, utility and investor interests without undermining financial returns is challenging, especially when considering varying consumption levels and discount rates.	The existing net metering framework is concluded to be appropriate for the current stage of the solar sector in Brazil, minimizing negative impacts on energy tariffs, distribution companies, consumers, and prosumers. Adjustments to net metering can be made without undermining investment in residential solar, offering guidance for future regulatory refinements.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Ghana The net metering policy in Ghana dates back to earlier frameworks under the Renewable Energy Act. The actual roll-out of net metering infrastructure and platforms accelerated after 2015, with national portals and streamlined application systems introduced around 2025 to support distributed solar connections (Amarteifo, 2026)	The net metering policy in Ghana aligns with the Scaling Up Renewable Energy Program (SREP). The new net metering digital platform and policies will support nationwide tracking of renewable energy installations in Ghana for the strategic implementation of SREP.	Grid readiness: Interconnection procedures and smart meter deployment must be expanded to support net-metered systems nationwide. Awareness and financing: Many potential prosumers face limited access to financing and lack awareness of the benefits of the policy.	Under SREP, the government plans to deploy 12,000 rooftop solar PV systems with net metering capability nationwide. This includes public facilities, small and medium-sized enterprises and household installations.
Philippines The net metering scheme in the Philippines is governed under the Renewable Energy Act (Republic Act 9513) and implementing regulations, with a modernized regime growing strongly post-2015 (Bellini, 2024).	In 2022, the policy cap was significantly increased from 100 kW threshold to 1 MW per installation, expanding eligibility for larger commercial and industrial rooftop solar systems.	Grid capacity and technical standards: Distribution utilities must upgrade interconnection protocols and smart metering infrastructure to accommodate two-way flows at scale. Incumbent utility resistance: Some utility companies fear reduced revenues, slowing adoption in certain regions.	The Energy Regulatory Commission (ERC) of the Philippines issued 13,189 certificates of compliance for 116.3 MW of total capacity to qualified end users under its net metering programme from 2015 until the end of June 2024.

Country	Main design characteristics	Main barriers and challenges	Impact achieved
Viet Nam Decision No. 11/2017/QĐ-TTg of 2017 on the Mechanism for Encouragement of the Development of Solar Power Projects in Viet Nam (Viet Nam, 2017).	The Ministry of Industry and Trade introduced a new scheme focusing on self-consumption, allowing excess energy sales to the grid of up to 20 per cent of total generation. The proposed tariff for surplus power matches the previous year's average electricity price. Reports indicate a rate of VND 671 (US\$0.026–0.027) per kWh. The Government is aiming for 50 per cent of office and residential buildings to use self-produced rooftop solar by 2030. In 2026, a draft decree from the Ministry is proposing that rooftop solar owners could sell up to 50 per cent of the energy produced back to the grid, in a bid to increase future uptake.	Extremely rapid rooftop deployment overwhelmed local distribution grids in some provinces. Curtailement and delayed grid connection approvals became common.	

Example variable renewable energy integration with grid-battery storage policies

Country	Main design characteristics	Main barriers and challenges	Impact achieved
South Africa South Africa is accelerating utility-scale battery storage through the Integrated Resource Plan (IRP) to stabilize the grid. Policy, including the Electricity Regulation Act amendments, enables private investment and encourages co-location with renewables (IEA no date).	Competitive tender programmes for utility-scale battery storage Inclusion of hybrid battery storage with renewables State backing of PPAs, with Eskom to lower off-taker risk International concessional financing	Delays due to lengthy negotiation processes Grid capacity constraints, especially for hybrid projects, causing project delays or cancellations	Contracted over 400 MW of hybrid battery storage, solar PV and wind projects under the Risk Mitigation IPP Programme. Awarded 360 MW of battery storage capacity under the first Battery Storage IPP tender, with a second tender for 1,200 MW planned.
Chile The energy transmission law (20.936) passed in 2016 and complemented by the Law on Energy Storage and Electromobility (Law 21.505) in 2022.	The energy transmission law was passed in July 2016 to modernize the electricity transmission system. It introduced planning mechanisms to expand the transmission infrastructure needed to integrate large-scale wind and solar. Energy storage systems and hybrid renewable-plus-storage plants are officially recognized within the electricity system. Additionally, the Law on Energy Storage and Electromobility allows stand-alone energy storage systems to participate in electricity markets. It enables storage operators to be compensated for supplying electricity during peak demand periods.	One of the most significant challenges has been transmission congestion and geographic imbalance. Most solar power plants are located in northern Chile, particularly in the Atacama Desert, where solar irradiation is extremely high. However, electricity demand is concentrated in central regions around Santiago. This geographic mismatch has created bottlenecks in transmission infrastructure, limiting the ability of the grid to absorb large volumes of solar generation.	Energy storage capacity in Chile reached 4.6 GWh in 2025.

Table 5.C3. Examples of available country-specific studies for national RE potentials

Name of institution	Technology coverage	Country/region coverage	Main characteristics
IRENA	- Solar PV - Concentrated solar power - Wind - Bioenergy	- Global; specific studies for Africa (all continental countries) (IRENA, 2014) - Indonesia (IRENA, 2017a) - Russian Federation (IRENA, 2017b) - South-eastern Europe (Ścigan et al., 2017) - Egypt (IRENA, 2018) and others	Provides studies on RE potential by country and/or technology The REmap project assesses RE potential from the bottom up, based on country analyses done in collaboration with country experts
Solutions Project (Stanford University)	- Solar PV - Concentrated solar power - Wind - Hydro - Wave and tidal	143 countries across Africa, Europe, Asia, North America, Latin America, and Oceania (The Solutions Project)	Provides a vision for the transition to 100 per cent wind, hydro and solar energy by 2050
Global Wind Energy Council	Wind	80 countries (e.g., United States of America, all European markets, India and China)	Provides country reports with (technical) potentials

Table 5.C4. Examples of publicly accessible databases on RE resource availability

Name of database	Public / private	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
Global Atlas for Renewable Energy (IRENA)	Public (free registration)	Solar, wind, hydro, geothermal, bioenergy and ocean	Global	Web-based platform coordinated by IRENA providing spatial data, maps and data sets on renewable energy resources and related infrastructure to support national and regional RE potential assessments	Both
Renewable Energy Data Explorer (Tran, Grue and Cox, 2018)	Public	Solar, wind, hydro, geothermal, biomass and wave	Selected developing countries	Interactive platform providing geospatial resource data, demand layers, grid infrastructure and analytical tools to support RE potential assessment and policy planning in developing countries	Both
NASA POWER (United States of America, National Aeronautics and Space Administration)	Public	Solar, wind and meteorological parameters	Global	Provides satellite-derived solar and meteorological data sets for energy, agriculture and climate applications; widely used as input data for RE potential calculations	Both
Photovoltaic Geographical Information System (Joint Research Centre)	Public	Solar PV	Europe, Africa, Asia and Americas	Online tool developed by the European Commission Joint Research Centre to estimate solar PV electricity yield using long-term climate data; results downloadable for analysis	Both
PVWatts (Dobos, 2013)	Public	Solar PV	Global (with regional resolution)	Online calculator estimating electricity generation from grid-connected PV systems using typical meteorological year data	RE potential

Name of database	Public / private	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
Renewables.ninja (Pfenninger and Stafell)	Public (free with limits)	Wind and solar	Global	Provides simulated hourly wind and solar power output time series based on meteorological reanalysis data; suitable for screening-level assessments	RE potential
Global Solar Atlas (World Bank Group)	Public	Solar PV, concentrated solar power	Global	Provides long-term average solar resource data and technical potential estimates using consistent global methodology, with country-level summaries	RE potential
Global Wind Atlas (DTU Department of Wind and Energy Systems and World Bank Group)	Public	Onshore and offshore wind	Global	High-resolution wind resource maps and technical potential estimates based on mesoscale and microscale modelling; widely used for national wind planning	RE potential
Global Geothermal Atlas (NLR)	Public	Geothermal	Selected developing countries	Provides geological, geophysical, and resource potential information for geothermal energy, supporting early-stage screening and planning	RE potential
FAOSTAT (Food and Agriculture Organization of the United Nations)	Public	Biomass	Global (focus on developing countries)	Data sets and tools on biomass availability, land use and sustainability constraints relevant for bioenergy potential assessment	Data for RE potential calculation
HydroSHEDS (World Wildlife Fund US)	Public	Hydropower	Global	High-resolution hydrographic data sets used as inputs for technical hydropower potential assessments at basin and national levels	Data for RE potential calculation

Name of database	Public / private	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
National RE atlases and zoning studies (Mexico, Ministry of Energy, 2023; India, Ministry of New and Renewable Energy, 'Wind and Solar Resource Map'; South African National Energy Development Institute, 'Wind Atlas for South Africa')	Public (country-specific)	Technology-specific	National	National or regional RE atlases (e.g., Mexico, India and South Africa) providing detailed, policy-relevant assessments of RE resource potential using local data	RE potential

Table 5.C5. Support tools to estimate RE potential per technology based on different parameters obtained from international databases

Technology	Needed/available information	Study/methodology for RE potential calculation based on available information	Calculation complexity
Solar PV	- Total solar panel area (m²) - Solar panel yield or efficiency (percentage) - Annual average solar radiation on tilted panels (shadings not included) - Performance ratio, coefficient for losses (range 0.5–0.9; default value 0.75)	Photovoltaic-software.com, under "Principles and resources"	Low

Technology	Needed/available information	Study/methodology for RE potential calculation based on available information	Calculation complexity
Solar PV	- System size (kW, DC) - Module type (standard, medium, thin film) - System losses (percentage) - Array type (fixed open rack, fixed roof mount, 1-axis, backtracked 1-axis, 2-axis) - Tilt angle (degrees) - Azimuth angle (degrees) - DC/AC ratio (optional) - Inverter efficiency (percentage)	The methodology behind PVWatts calculations (see table 5.C4) can be applied to data outside the PVWatts calculator. The methodology is available from the PVWatts manual (Dobos, 2013).	Medium
Wind	ρ = air density (kg/m³) - A = rotor swept area (m²) - C_p = coefficient of performance - V = wind velocity (m/s) - N_g = generator efficiency - N_b = gear box bearing efficiency	Several websites or papers available (e.g., Massachusetts Institute of Technology (MIT); Sarkar and Behera, 2012); Windpowerengineering.com)	Low
Biomass electricity	Depends on desired output	A6.4-AMT-007: Emissions from electricity generation and consumption	High

Technology	Needed/available information	Study/methodology for RE potential calculation based on available information	Calculation complexity
Geothermal	Depends on desired output, but most important are: ▪ Surface temperature ▪ Heat flow ▪ Density of earth material ▪ Depth of heat source	Beardsmore et al. (2011)	Medium

Tables 5.C6–5.C10 present the key design characteristics of selected RE policy instruments – including FiTs, auctions, tax incentives, net metering and VRE integration with grid-battery storage policies – and explain how each characteristic may influence the technical potential during the assessment period. The tables focus on those policy design elements most likely to affect whether the estimated technical potential can be realized in practice. These include eligibility criteria, differentiation mechanisms, incentive or payment structures, duration and stability of support, grid access and integration

requirements, technical standards and administrative or regulatory conditions.

The purpose of these tables is not to provide a comprehensive analysis of each instrument, but rather to support users in:

- Identifying relevant policy design features in their national context.
- Understanding how these features may enable or constrain RE deployment.
- Qualitatively assessing their likely influence on the probability of achieving the technical potential during the assessment period.

Table 5.C6. Feed-in tariff policies – influence of policy design characteristics on technical potential

Design characteristic	Description	Influence on technical potential for the assessment period
Eligibility	▪ Project owner ▪ Technology ▪ Size ▪ Location	The narrower the eligibility conditions of the FiT policy, the lower the probability that the policy achieves its technical potential for the assessment period.

Design characteristic	Description	Influence on technical potential for the assessment period
Tariff differentiation	- RE type - Project size - Resource quality - Technology application - Ownership type - Geography - Local content	Differentiated tariffs are able to tap into a larger share of the GHG emissions reduction potential; lower tariffs for less expensive RE technologies may lower the probability that the policy achieves its technical potential for the assessment period.
Payment structure	Fixed price or premium price policies	For both types of payment structures, if the resulting end price is above the LCOE or other feasibility calculations done by power producers, this should not reduce the probability that the policy achieves its technical potential for the assessment period.
Utility's role	- Purchase obligation - Guaranteed grid connection	The lack of purchase obligation or guaranteed grid connection may lower the probability that the policy achieves its technical potential for the assessment period, because of decreased security and certainty for investors.
Contract and payment duration	Contract periods (short term, medium term, long term)	A short contract period in combination with a relatively low FiT might lower the probability that the policy achieves its technical potential for the assessment period because of a lack of certainty for power producers and their investors. Conversely, a short contract period with a relatively high FiT might be attractive, since it allows the initial investment to be recouped relatively quickly. Longer contract periods mean higher risks for power producers; power producers may lack confidence in the Government's ability or will to sustain the FiT over time; and their own costs are more difficult to forecast further out. Longer contract periods might therefore lower the policy's technical potential for the assessment period.

Design characteristic	Description	Influence on technical potential for the assessment period
Opt-out options	Contractual opt-out options for power producers to sell energy on the free market	Power producers gain contractual flexibility, after a certain time, to sell their electricity on the free market instead of receiving the FiT. This can increase investment interest in country contexts where RE technologies might achieve cost parity in the near- to mid-term future.
Forecasting	Forecast obligation	Forecasting obligations require power producers to provide hourly predictions of power production to participate in the market. The actual production under the estimated forecast is charged the highest price on the market for the non-produced amount of energy. This presumably has a small effect on the likelihood that the policy achieves its technical potential for the assessment period, but may slightly increase project costs.
Grid access	- Transmission - Interconnection	A lack of grid priority for RE electricity presumably lowers the probability that the policy achieves its technical potential for the assessment period, because of decreased security and certainty for investors.
Policy adjustments	- Payment adjustments (fixed adjustments, regular adjustments, inflation adjustments) - Programme adjustments	Downward adjustment of FiT prices or premiums may decrease the probability that the policy achieves its technical potential for the assessment period if done ineffectively, and may also lead to resistance.

Sources: Adapted from Cory, Couture and Kreycik (2009); Couture et al. (2010); Rickerson et al. (2012); United Nations Economic and Social Commission for Asia and the Pacific (2012).

Table 5.C7. Tax incentive policies – influence of policy design characteristics on technical potential

Design characteristic	Description	Influence on technical potential for the assessment period
Type of tax incentive	▪ Reduced or complete tax exemption or refunds ▪ Deductibles ▪ Tax credits ▪ Different payment schedules ▪ Fiscal stability incentives	▪ Tax incentives that are too low provide insufficient incentives for eligible entities to install additional RE capacity, thus lowering the probability that the technical potential for the assessment period is achieved. ▪ Incentive policies incentivize RE in different ways: tax credits reducing the tax liability for (a portion of) the cost of purchasing and installing RE capacity lead to direct cost saving; fiscal stability incentives that shield certain RE technologies from potential future changes in fiscal regimes or from additional fees create a stable investment environment; decreased stability and a low level of incentives lower the probability that the technical potential for the assessment period is achieved.
Scope of application	▪ Pre-investment expenses related to RE projects ▪ Sale of electricity ▪ Carbon credits and other ancillary income ▪ RE-specific taxes or concession fees ▪ Services and equipment ▪ Civil works	▪ A narrow scope of tax incentive (potentially) decreases the incentive for eligible entities to install additional RE capacity, lowering the probability that the technical potential for the assessment period is achieved. ▪ Restricted eligibility that is limited to a few RE technologies may lower the probability that the technical potential for the assessment period is achieved, because eligible entities have less flexibility to choose the most appropriate technology.

Sources: Adapted from OECD (2011); North Carolina Solar Center (2012); Cabré et al. (2015b).

Table 5.C8. Auction policies – influence of policy design characteristics on technical potential

Design characteristic	Description	Influence on technical potential for the assessment period
Auction demand and auction design	Choice of the volume auctioned, and differentiation between different technologies and project sizes (technology-neutral auctions or technology-specific auctions, and stand-alone or systematic auctioning policies)	- The volume auctioned directly affects the size of the technical potential for the assessment period. - Suboptimal auction design and/or incomplete pre-analysis on conditions for successful tendering may affect the auction's effectiveness and decrease the likelihood that the policy will achieve its technical potential for the assessment period.
Longevity of the PPA	- PPA signed with the preferred bidder - Contract provides power producers with a fixed price for a certain number of years and guaranteed purchase for all generation	Without the provision of longevity annuities, which safeguard against risks for power producers and investors, and lower the costs of financing, there is a reduced likelihood that the technical potential for the assessment period will be achieved.
Qualification requirements	- Power producers eligible to participate in the auction and requirements related to reputation - Equipment and production site selection - Securing grid access - Instruments to promote local socioeconomic development	- A lack of qualification criteria for bidders may decrease the likelihood that expected capacity is successfully installed and that the technical potential for the assessment period is achieved. - High and costly qualification requirements may exclude small-scale or new power producers, since such potential bidders may lack required resources; this may decrease the likelihood that the technical potential for the assessment period is achieved. - Identification of sites that lack ideal resources and secured grid connection potentially increases risks to investors, thus decreasing the likelihood that the technical potential for the assessment period is achieved.

Design characteristic	Description	Influence on technical potential for the assessment period
Winner selection process	▪ Bidding procedure ▪ Requirements of minimal competition ▪ Winner selection criteria ▪ Clearing mechanism and marginal bids ▪ Payment to the auction winner	▪ Competitive bidding (in sealed-bid or descending clock auctions) can lead to underbidding due to an incentive for bidders to bid as low as possible to increase their chances of securing a contract, which may decrease the likelihood that the technical potential for the assessment period is achieved. ▪ Experience suggests that underbidding is widespread and contract failure rates remain high, leading to slower growth.

Sources: Adapted from Lucas, Ferroukhi and Hawila (2013); Ragwitz et al. (2014); Ferroukhi et al. (2015).

Table 5.C9. Net metering policies – influence of policy design characteristics on technical potential

Design characteristic	Description	Influence on technical potential for the assessment period
Eligibility criteria	Determines who can participate in the net metering scheme, e.g., ▪ Residential, commercial, industrial users ▪ Types of RE technology	Broader eligibility increases participation and thus the probability of achieving the technical potential. Narrow eligibility reduces this likelihood.
Payment scheme	Payment scheme for excess energy supplied back to the grid (e.g., retail rates, fixed rate).	A more favourable payment scheme enhances adoption by making net metering financially appealing, while less favourable rates may discourage participation.
System capacity limits	Maximum capacity limits for net-metered systems (e.g., kWh or percentage of total grid demand)	Low system capacity limits may restrict the scale of RE deployment, reducing the technical potential.
Programme caps	Overall caps on net-metered capacity	Any cap will restrict the technical potential.

Design characteristic	Description	Influence on technical potential for the assessment period
Grid interconnection standards	Technical requirements to connect to grid	Unclear or very stringent requirements may reduce technical potential.

Table 5.C10. Variable RE integration with grid-battery storage policies – influence of policy design characteristics on technical potential

Design characteristic	Description	Influence on technical potential for the assessment period
Long warranty (10–15 years)	Long warranty requirement of 10–15 years, for example	Only large vendors can offer such long performance guarantees
Mandatory operation and maintenance requirement	Mandatory operation and maintenance requirement of 5–10 years, for example	Smaller or regional players may not have local service teams
Turnkey engineering, procurement, and construction requirement	Supplier becomes responsible for both installation and commissioning of the system	Narrows the field to large, vertically integrated companies
High experience threshold	E.g., “At least 3 similar projects”	Excludes new entrants
Strict integration requirements	- Strict grid code compliance - Integration with SCADA/EMS	- Limits bidders unfamiliar with national technical standards - Requires deep technical knowledge of utility systems
Discharge duration and capacity requirements	Storage capacity requirements and discharge duration allowed	High-capacity requirements may discourage small vendors and long discharge duration may require expensive batteries
Reliability and performance standards	High minimum availability guarantee (95 per cent, for example) for storage system	Hard to commit unless vendor has maintenance responsibility also

Design characteristic	Description	Influence on technical potential for the assessment period
Battery degradation guarantees	Battery degradation guarantees over a long period (e.g., 10+ years)	Not all battery chemistries can maintain performance over 10+ years
High technical requirements	Requirements such as high round-trip efficiency ¹¹ (≥ 85%)	Can exclude lower-cost chemistries or older technologies

11. This ensures battery can store and release energy more efficiently during charge and discharge cycles, providing longer use time.

Table 5.C11. Barrier assessment template – simultaneous rating method

Barrier category	Barrier description	Severity score (1–5)
Institutional	Lack of interministerial coordination	4
Technical	Grid stability concerns with high VRE	5
Financial	High transaction costs for small-scale PV	3

Table 5.C12. Barrier assessment example – pairwise comparison method

Number of barriers identified	to	Rating matrix							Standardized matrix V							Row total	Weighting vector w
		Barrier A	Barrier B	Barrier C	Barrier D	Barrier E	Barrier F	Barrier G	Barrier A	Barrier B	Barrier C	Barrier D	Barrier E	Barrier F	Barrier G		
Barrier A		1	0.2	5	2				0.15	0.1	0.4	0.2				0.92	0.23
Barrier B		5		1	4	5				0.75	0.61	0.3	0.6			2.27	0.57
Barrier C		0.2	0.25	1	0.5				0.03	0.15	0.08	0.1				0.32	0.08
Barrier D		0.5		0.2	2	1				0.07	0.12	0.17	0.12			0.48	0.12
Barrier E																	
Barrier F																	
Barrier G																	
Column total		6.7		1.7	12.0	8.5											1.00

Source: Adapted from Böttcher et al. (2011).

Table 5.C13. - Table 5.C15.

Summarized results for renewable energy addition considering design characteristics, financial feasibility and other barriers under different policies

Table 5.C13. Summary of RE addition under FiT policy (example 2)

Step	RE addition (MW)	Adjustment	% reduction
Step 1: Estimate technical potential	1,300	—	—
Step 2: Account for policy design characteristics	800	-500	38

Step	RE addition (MW)	Adjustment	% reduction
Step 3: Account for financial feasibility	600	-200	25
Step 4: Account for other barriers	262 to 329	-271 to -338	45 to 56

Table 5.C14. Summary of RE addition under net metering policy (example 3)

Step	RE addition (MW)	Adjustment	% reduction
Step 1: Estimate technical potential	500	—	—
Step 2: Account for policy design characteristics	250	- 250	50
Step 3: Account for financial feasibility	200	-50	20
Step 4: Account for other barriers	90 to 130	-70 to -110	35 to 55

Table 5.C15. Summary of RE addition under VRE integration with grid battery storage policy (example 4)

Step	RE addition (MW)	Adjustment	% reduction
Step 1: Estimate technical potential	40	—	—
Step 2: Account for policy design characteristics	35	-5	13
Step 3: Account for financial feasibility	30	-5	14
Step 4: Account for other barriers	16 to 25	-5 to -14	16 to 46

Box 5.C1. Hierarchy of RE potential – IPCC definitions

Theoretical potential is derived from natural and climatic (physical) parameters (e.g., total solar radiation on a continent's surface). The theoretical potential can be quantified with reasonable accuracy, but the information is of limited practical relevance. It represents the upper limit of what can be produced from an energy resource based on physical principles and current scientific knowledge. It does not take into account energy losses during the conversion process necessary to make use of the resource, nor any barriers.

Technical potential refers to the renewable energy output achievable with full implementation of proven technologies, without considering economic costs or other barriers.

Sustainable development potential is the amount of RE output that would be obtained in an ideal setting of perfect economic markets, optimal social (institutional and governance) systems, and achievement of the sustainable flow of environmental goods and services. This is distinct from economic potential because it explicitly addresses intergenerational and intragenerational equity (distribution) and governance issues.

Economic potential is the amount of RE output projected when all social costs and benefits related to that output are included, there is full transparency of information, and it is assumed that exchanges in the economy install a general equilibrium characterized by spatial and temporal efficiency. Negative externalities and co-benefits of all energy uses, and other economic activities, are priced at social discount rates to balance the interests of consecutive human generations.

Market potential is the amount of RE output expected to occur under forecasted market conditions, shaped by private economic agents and regulated by public authorities. Private economic agents realize private objectives within given, perceived and expected conditions. Market potentials are based on expected private revenues and expenditures, calculated at private prices (incorporating subsidies, levies and rents) and with private discount rates. The private context is partly shaped by public authority policies.

Source: Edenhofer et al. (2012).

Note on examples

The examples provided in boxes 5.C2–5.C13 illustrate the application of the four-step approach to selected RE policy types. The analytical steps – estimating technical potential, accounting for policy design characteristics, incorporating financial feasibility considerations and addressing other barriers – are identical across all five policy types covered by this methodology. For example 1 on auction policies, please refer back to chapter 5. Example 2 refers to FiT policies. Example 3 refers to net metering policies. Example 4 refers to VRE policies.

To avoid duplication, the four-step approach is not elaborated separately for tax incentive policies. However, users should apply the same structured logic when assessing any of the five policies. Differences across policy types relate primarily to their specific policy design characteristics and the nature of the barriers encountered, rather than to the underlying analytical approach. Therefore, when assessing tax incentive policies, users should apply the same methodological steps throughout the assessment while referring to Table 5.C7 to identify and account for the relevant policy design characteristics.

Box 5.C2. FiT (example 2) – estimating technical potential for the assessment period for a FiT policy without a policy cap

1. Estimate technical potential for the assessment period

As the feed-in tariff policy specifies no policy cap for any of the assessment period years, the user follows the approach outlined under **Case II: policy without policy cap set for entire assessment period**. A national university with expertise and a progressive energy department produces estimates for the maximum RE resource potential in the country, which they have been updating on a yearly basis for their own research purposes. In a workshop session, the university experts explain their estimates for the RE resource potential, and the underlying assumptions on all resource and technical factors, to ministry representatives. Both groups jointly conclude that the long term technical potential for the respective technologies is: It is a key recommendation to prioritise a policy for assessment following the steps outlined in this section:

- solar energy – 1,500 MW
- wind energy – 800 MW

The experts further analyse capacity and, given the trajectory of RE implementation, determine that it is practical to install the following by 2030 (NDC target year):

- solar energy – 900 MW
- wind energy – 400 MW

Therefore, the overall technical potential of the feed-in tariff policy across technologies for the assessment period by 2030 is determined to be 1,300 MW.

1,300 MW

Box 5.C3. Net metering (example 3) – estimating technical potential for the assessment period for a net metering policy without a policy cap

1. Estimate technical potential for the assessment period

As the **net metering policy** does not impose any limits on installed capacity for the assessment period, the user follows the approach outlined under **Case II: Policy Without Capacity Limits for the Entire Assessment Period**.

A **leading energy research institute**, recognized for its work in renewable energy (RE) and grid integration, has been conducting detailed studies on the potential for distributed solar energy systems in the country. These studies are updated biennially and include comprehensive assessments of rooftop solar potential, considering factors such as rooftop availability, consumer adoption rates, and grid stability.

During a **technical consultation meeting**, the institute's researchers present their findings on the solar energy potential and explain the underlying assumptions. After

discussions, the institute and government representatives agree on the following long-term technical potential for net metering:

Solar Energy (Rooftop/Distributed Generation): 700 MW

The researchers also analyze current market trends, policy incentives, and implementation challenges. Based on this analysis, they determine that it is feasible to achieve the following installed capacity by 2030 (the NDC target year):

Solar Energy (Rooftop/Distributed Generation): 500 MW

Therefore, the **overall technical potential** of the net metering policy for the assessment period by 2030 is determined to be **500 MW**.

500 MW

Box 5.C4. VRE integration with grid-battery storage (example 4) – estimating technical potential for the assessment period for a VRE integration with grid-battery storage policy without a policy cap

1. Estimate technical potential for the assessment period

The policy is designed to help the integration of VRE with the grid using grid-level battery storage. The implicit assumption is that the country is having problems with VRE integration. Battery storage has several applications but only integration of VRE in the grid has been covered here.

Unlike the technical potential of RE sources such as wind or solar energy, grid-level battery storage potential for VRE integration varies over years based on various factors, primarily VRE generation. To estimate the storage potential over multiple years, we can use a simple scaling method based on projected VRE growth and curtailment trends.

Approach: If the policy does not define a capacity cap, use a standard 10 per cent ratio (known as “Storage to VRE ratio”) as a starting point. For example, estimate the technical potential for storage as 10 per cent of the peak VRE capacity, assuming a 4-hour discharge duration.

i. Project future VRE generation

VRE generation_t = VRE generation₀ × (1+g)^t, where
g = annual growth rate of VRE; t = years

ii. Estimate curtailment rate: This is the percentage of VRE wasted but can be assumed to decrease over period as grids improve and become flexible.

iii. Calculate annual battery energy (GWh)

Battery (GWh)_t = VRE generation_t × Curtailment rate_t × Coverage factor / (Battery cycles/year)

Coverage factor = Fraction of curtailed energy stored (e.g., 0.6)

Battery cycles/year = Battery charge/discharge cycles (e.g., 300 in case of daily use, assuming battery used for 300 days in a year)

iv. **Energy lost**

Account for energy lost during charging and discharging by applying a round-trip efficiency (RTE) factor (e.g., 85–90 per cent for lithium-ion batteries). Multiply the calculated battery energy in step (iii) by this factor to ensure GHG reduction estimates (chapter 6) are realistic and conservative.

v. **Calculate battery power (GW)**

Battery (GW)_t = Battery (GWh)_t / Storage duration (h)
Storage duration (h): Hours of battery discharge (e.g., 4 hours for solar smoothing)

Example projection

Year	VRE (GWh)	Curtailment rate	Curtailed (GWh)	Battery energy (GWh)	Battery power (GW)*
2025	500	15%	75	0.15	0.0375
2030	805	10%	80.5	0.16	0.04
2035	1,300	8%	104	0.21	0.0525

Note:

Power (GW) = Energy (GWh) ÷ 4h

Battery needs to grow more slowly than VRE if curtailment improves.

37–52 MW

Examples on effect of policy design characteristics on expected renewable energy addition of the policy (boxes 5.C5–5.C7.)

Box 5.C5. FiT (example 2) – using policy design characteristics to refine expected RE addition for the assessment period

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics

The design characteristics for the feed-in tariff are as follows:

- **Eligibility** – the only technology eligible under the feed-in tariff is solar PV.
- **Tariff differentiation** – higher feed-in tariffs for small projects and lower tariffs for large-scale projects (set to give rates of return of 5–8%).
- **Payment structure** – premiums offered above prevailing retail rates for electricity.
- **Utility role** – government-owned single buyer with guaranteed purchase.
- **Contract and payment duration** – premium is offered over period of 15 years.
- **Forecasting** – no forecasting requirements.
- **Grid access** – grid priority transmission and dispatch for RE.
- **Policy adjustments** – only inflation adjustments over lifetime of feed-in tariff.

Because of a lack of specific quantification methods, a qualitative approach is used to estimate the influence of each design characteristic (above) on the technical potential for the assessment period of the policy.

To start, the user made first order estimates of how each policy design characteristic might influence the technical potential for the assessment period. These estimates were discussed in a consultation workshop with national energy sector experts. The analysis reveals that the policy design characteristics that are most likely to affect the technical potential for the assessment period are as follows:

1. The scope of eligibility is expected to directly reduce the technical potential for the assessment period, since only solar PV installations are eligible. As a result, the technical potential for the assessment period for wind energy, which was determined to be 400 MW, is deducted from 1,300 MW, leaving 900 MW as the technical potential of the policy.
2. The approach of offering a premium on top of prevailing market prices for electricity is expected to reduce the technical potential for the assessment period, because the partial dependence on the electricity market price introduces a level of uncertainty that would not exist if the entire feed-in price was fixed. A local consultancy conducted a representative survey of potential power producers and investors (both small scale and large scale) on how this uncertainty might affect future RE deployment. Based on this survey, the local consultants estimate that the uncertainty

reduces the technical potential for the assessment period by only about 60 MW (conservative estimate), because most power producers have found ways to deal with the uncertainty (e.g. through integrating it into the rest of their portfolio). This reduces the technical potential for the assessment period to 840 MW.

3. The contract and payment duration of 15 years is expected to be too short for several large-scale solar PV projects because power producers would require contracts with payment durations of 20–25 years. A consultation with two local experts on RE investments, which includes a review of the projects currently in the pipeline in the country, reveals that, under these conditions, about 6% of the projects in the pipeline would not be built. This means that the technical potential for the assessment period would be further reduced by 40 MW (conservative estimate) to 800 MW.

After accounting for all policy design characteristics, the refined technical potential for the assessment period is expected to be 800 MW (compared with 1,300 MW originally).

800 MW

Box 5.C6. Net metering (example 3) – using policy design characteristics to refine expected RE addition for the assessment period

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics

The design characteristics for the net metering policy are as follows:

- **Eligibility criteria:** Residential, commercial, and industrial users are eligible, but restrictions apply to only solar PV technology is eligible. These restrictions narrow participation, reducing the technical potential by 50 MW, from 500 MW to 450 MW.
- **Payment scheme:** The policy compensates residential and commercial users for excess energy at retail rates but offers only fixed rates for industrial users. This less favorable payment scheme discourages participation, especially for industrial users. Experts estimate this reduces the technical potential by 100 MW, leaving 350 MW.
- **System capacity limits:** The policy caps system capacity at 5 kW for residential users, 50 kW for commercial users, and 500 kW for industrial users. These restrictive limits, especially for industrial users, significantly reduce the potential. This further decreases the technical potential by 100 MW, leaving 250 MW.

After accounting for all policy design characteristics, the refined technical potential for the assessment period is 250 MW, compared to the original estimate of 500 MW.

250 MW

Box 5.C7. VRE integration with grid-battery storage system (example 4) – using policy design characteristics to refine expected RE addition for the assessment period

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics

This example highlights how specific design requirements can influence the technical potential of a grid-scale battery storage system, particularly in the context of utility-owned models. It is important to note that such detailed design specifications may not always be required in utility-owned battery storage projects, or only a subset may be applicable. In other models, their relevance depends on the conditions outlined in the request for proposal.

To simplify the illustration, only a few representative requirements are considered:

Based on a technical potential assessment for VRE integration by 2030, a utility decided to issue a request for proposal inviting IPPs to supply the required battery storage capacity. The request for proposal included the following conditions:

- **15-year warranty:** Only large vendors are typically able to offer such long-term performance guarantees, which limits competition.
- **Minimum of three years' experience in similar projects:** This requirement further restricts the pool of bidders by excluding newer or local entrants.
- **Strict compliance with national grid codes and integration with SCADA/EMS:** These technical requirements may pose barriers for some bidders, especially those unfamiliar with national standards or lacking in utility-level system integration experience.
- **Required capacity of 40 MW with 6-hour discharge duration:** This high capacity and long duration favour expensive battery chemistries and may discourage participation from smaller vendors.
- **Minimum availability of 95 per cent:** Ensuring such a high level of system availability could be challenging for some suppliers and may raise costs.

Stakeholder consultations were held to assess the feasibility of these design choices. Based on feedback, it was concluded that, under the specified conditions, no more than 35 MW of grid battery storage capacity could realistically be installed by 2030.

35 MW

Examples on effect of financial factors on expected renewable energy addition of the policy (boxes 5.C8–5.C10)

Box 5.C8. FiT policy (example 2) – using financial factors to refine expected RE addition of the policy for the assessment period

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics - 800 MW

3. Account for effect on financial feasibility of RE technologies

The LCOE calculations for the country revealed costs between **10 cents/kWh** and **17 cents/kWh** for various locations. Since the solar potential can be roughly divided into four geographic areas, four different representative full load hour estimates were used to estimate these location-specific LCOE costs. The feed-in tariff rate is fixed at **13 cents/kWh**. Solar PV will likely be developed in only two of the four geographic areas in which the LCOE is above the wholesale electricity price (i.e. the feed-in tariff rate). As the two regions in which no solar PV will be developed have a total maximum capacity of **100 MW** (relatively low as a result of low solar radiation and swampy regions where only limited capacity could be installed), this reduces the technical potential for the assessment period of the policy from **800 MW to 700 MW**.

Since both stand-alone and rooftop installations are eligible under the feed-in tariff, financial factors should not further reduce the technical potential for the assessment period in the two geographic areas with higher solar potential, as both areas have meaningful electricity loads and ample space available to build the plants.

The feed-in tariff provides a large degree of certainty to the investor, thereby attracting financing even from risk-averse sources. However, access to finance in general is limited in the country. Even with the guarantee provided by the feed-in tariff, the number of investors will be small. Therefore, after consultation with financial experts in the country, the technical potential for the assessment period is further refined from 700 MW to 600 MW.

600 MW

Box 5.C9. Net metering policy (example 3)– using financial factors to refine expected RE addition of the policy for the assessment period

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics - 800 MW

3. Account for effect on financial feasibility of RE technologies

For a typical solar project with a lifespan of 15 years, the Levelized Cost of Electricity (LCOE) is calculated based on the initial installation cost and ongoing maintenance expenses. In regions where net metering is implemented, excess energy generated by the solar systems can be fed back into the grid. This causes the electricity meter to run backward, allowing the electricity producer to reduce their energy bill by offsetting their consumption with the excess solar energy generated. This feature enhances the financial viability of solar projects and can further impact the overall LCOE, making solar energy even more cost-effective for consumers.

Analyzing LCOE across different locations in the country revealed a cost range of **10 to 17 cents per kilowatt-hour (kWh)**. Given that the country's solar potential is broadly categorized into three geographic regions, four representative estimates of full-load hours were used to determine location-specific LCOE values.

The fixed electricity purchasing price is set at **14 cents/kWh**. As a result, solar PV development is expected to occur only in the region where the LCOE exceeds this wholesale electricity purchasing price. Consequently, the technical potential for solar deployment during the policy assessment period is reduced from **250 MW to 200 MW**.

200 MW

Box 5.C10. VRE integration with grid-battery storage policy (example 4) – using financial factors to estimate impact on technical potential of the policy for the assessment period

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics - 800 MW

3. Account for effect on financial feasibility of RE technologies

This example illustrates impact of financial factors on technical potential. It is assumed the utility planned to own the battery system, with partial support from concessional financing.

Key financial factors and their impact:

1. **Impact of changed LCOE due to battery storage:** Battery storage, though it helps to address curtailed VRE, increased CAPEX and operation and maintenance costs, can

also increase LCOE. In the standard LCOE formula (see Appendix 5.C1), the revised LCOE needs to be calculated considering that CAPEX should now also include cost of battery, its operation and maintenance costs, and replacement costs over the plant lifetime. Battery charging costs (LCOE of the VRE) should also be included in the fuel costs, assuming battery is being charged from the plant's own VRE. On the other hand, electricity delivered also needs to be adjusted; this should be net electricity delivered, consisting of VRE generation net of curtailment, battery charging and losses, but inclusive of battery discharge. (Note modified formula included in Appendix 5.C1.)

Technical potential can be reduced if the utility is not allowed to pass on the increased cost to consumers. It will depend on the level of increase in LCOE, and expert consultations can be carried out to estimate the impact on technical potential. No impact is considered here, assuming the increased use of curtailed electricity through battery use will cancel out the impact of increased costs.

2. Other important financial factors

These can be considered in this step or along with other barriers in the next step "Account for barriers".

- **High capital cost (CAPEX):** The unit cost of the required battery system (with long discharge duration and high availability) was found to be higher than expected due to limited vendor competition from the design stage. This increased the need for upfront investment.
- **Limited budget availability:** The utility had budgetary constraints and could only allocate a fixed amount for battery procurement within the current 5-year plan. The higher CAPEX per MW reduced the feasible procurement size.
- **No dedicated tariff recovery mechanism:** The national regulatory framework did not yet allow the utility to pass on battery investment costs through a separate tariff component. This made cost recovery uncertain and discouraged full-scale deployment.
- **No ancillary services revenue allowed:** The utility was not permitted to earn separate revenue from frequency regulation or other ancillary services, limiting the economic value of the battery.
- **Partial concessional finance:** Although a portion of the funding was available at concessional terms through a climate fund, the loan tenor and coverage were not sufficient to fully offset the high CAPEX.

Outcome:

After factoring in these financial constraints, consultations with stakeholders, including finance and regulatory teams indicated that the utility could realistically finance and deploy only 30 MW of battery storage under current conditions, even though the technical potential was higher.

30 MW

Examples on effect of other barriers on expected renewable energy addition of the policy (boxes 5.C11–5.C13)

Box 5.C11. FiT (example 2) – accounting for other barriers to refine expected RE

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics - 800 MW

3. Account for effect on financial feasibility of RE technologies - 600 MW

4. Account for other barriers

In **step 1**, the main barriers for the feed-in tariff are identified using the list of barrier categories in Table 5.2:

- **Technical** – no technical standard for rooftop solar PV installations, which has resulted in no domestic technology providers for rooftop solar PV installations
- **Regulatory and policy uncertainty** – history of numerous ad hoc policy changes and adjustments, leading to a general lack of transparency and uncertainty for market actors
- **Institutional and administrative** – permits for new RE plants are difficult to obtain because approval procedures are lengthy, non-transparent, and cumbersome
- **Market** – existing fossil fuel subsidies for low- and medium-income households
- **Financial and budgetary** – concerns about the financial solvency of only state-owned utilities, with a history of defaults
- **Infrastructure** – none
- **Lack of skilled personnel** – lack of skilled personnel to install solar PV panels
- **Public acceptance and environmental** – none

In **step 2**, the severity of each identified barrier is evaluated and rated on a scale of 1 to 5, with 5 indicating very severe:

- No technical standard and no domestic technology providers for rooftop PV installations – **5 (very severe)**
- Policy uncertainty due to a history of ad hoc policy changes and adjustments – **2 (low to medium)**
- Slow and non-transparent permit approval process – **3 (medium)**
- Existing fossil fuel subsidies for low- and medium-income households – **1 (low)**
- Concerns about financial solvency of only state-owned utilities with a history of defaults – **3 (medium)**
- Lack of skilled personnel to install solar energy panels – **2 (low to medium)**

In step 3, other policies are identified that may help the feed-in tariff policy overcome barriers to RE deployment. For example, a separate policy enacted to address the slow and non-transparent permit approval process helps overcome this barrier. The Ministry of Energy is currently carrying out a comprehensive reform of the entire approval process as a result of new anti-corruption legislation. Thus, the permit approval process will be entirely redesigned to promote a faster and more transparent process. Even though the reform process may require a transitional phase, it is deemed sufficient to overcome the barrier.

In step 4, the effect of barriers on the technical potential for the assessment period is estimated. The extent of this effect is based on expert judgment:

- **No technical standard and no domestic technology providers for rooftop solar PV panels** – This barrier is categorized as very severe (in step 2), indicating that few installations can be expected for rooftop solar PV installations under the feed-in tariff policy. A national university has estimated that **50 MW** of the **800 MW** technical potential for the assessment period of the policy directly links to rooftop installations. This figure is therefore reduced by **50% to 25 MW**, which is subtracted from the policy's impact of **600 MW**, resulting in **575 MW**.
- **Policy uncertainty due to history of ad hoc policy changes and adjustments** – minus **5–8%** (applies to total expected RE addition of the policy for the assessment period), based on the assessment of how policy uncertainty affects investor behavior using survey data from a small representative sample of investors.
- **Slow and non-transparent permit approval process** – the barrier is overcome by other policy intervention to reform the permit approval process (discussed under step 3).
- **Existing fossil fuel subsidies for low- and medium-income households** – minus **3–4%** (general level), based on experience with household behavior in the past.
- **Concerns about financial solvency of only state-owned utilities with a history of defaults** – minus **20–30%** (general level), based on the assessment of how policy uncertainty affects investor behavior using survey data from a small representative sample of investors.
- **Not enough skilled personnel to install solar energy panels** – minus **20%** (technology level), based on market assessment of the number of skilled personnel available to install solar energy panels.

As the impact of the lack of skilled personnel to install solar PV panels partially overlaps with the impact of no domestic technology providers for rooftop solar PV panels, the barrier-specific impacts cannot be fully aggregated. As the overlap accounts for about 5%, the total effect of the barriers is between **43% and 57%**.

The barrier analysis therefore suggests that the feed-in tariff will increase RE generation by between **262 MW and 329 MW**. The range represents the uncertainty associated with the identified barriers.

262–329 MW

Box 5.C12. Net metering (example 3) – accounting for other barriers to refine expected RE

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics - 800 MW

3. Account for effect on financial feasibility of RE technologies - 600 MW

4. Account for other barriers

In step 1, the main barriers for the feed-in tariff are identified using the list of barrier categories in Table 5-10:

- **Technical** : Inadequate grid infrastructure to handle bi-directional energy flow, leading to delays in the implementation of net metering.
- **Regulatory and policy uncertainty**: Lack of clear, stable regulations and guidelines for net metering policies, creating uncertainty among potential investors and consumers.
- **Institutional and administrative**: Complex approval process for net metering system installations, requiring lengthy permits and approvals that delay deployment.
- **Market** : Market resistance due to existing fossil fuel subsidies that make electricity from the grid cheaper than solar-generated power for some consumers.
- **Financial and budgetary**: High initial capital cost for solar PV installations, making it harder for consumers to adopt net metering, especially in lower-income brackets.
- **Infrastructure**: Lack of advanced metering systems that can measure bi-directional flow of energy (generation and consumption) and manage credits for net metering.
- **Public acceptance and environmental**: Lack of awareness about the long-term benefits of net metering and solar energy.

In step 2, the severity of each identified barrier is evaluated and rated on a scale of 1 to 5, with 5 indicating very severe:

- Inadequate grid infrastructure to handle bi-directional energy flow – 4 (high)
- Lack of clear and stable regulations for net metering – 3 (medium)
- Complex approval process for net metering system installations – 3 (medium)
- Existing fossil fuel subsidies making grid electricity cheaper than solar-generated power – 4 (high)
- High initial capital cost for solar PV installations – 4 (high)
- Lack of advanced metering systems for measuring bi-directional energy flow – 4 (high)
- Public skepticism or lack of awareness about the benefits of net metering – 2 (low to medium)

In step 3, account for other policies addressing barriers

- Grid infrastructure policy upgrades and investments.
- Government initiatives aimed at simplifying renewable energy regulations (e.g., energy regulatory bodies working on clearer net metering standards).
- Administrative simplification policies, such as faster approval processes for renewable energy installations.
- Fossil fuel subsidy reform policies that phase out subsidies to encourage cleaner energy sources.
- Subsidy or grant programs aimed at reducing the upfront costs of solar systems (e.g., green financing options, solar rebate programs).
- Ongoing upgrades to smart metering infrastructure in some regions.
- Public awareness campaigns promoting the benefits of solar energy and net metering.

In step 4, the effect of barriers on the technical potential for the assessment period is estimated. The extent of this effect is based on expert judgment:

- Inadequate grid infrastructure – Barrier is categorized as severe (step 2), limiting the technical potential of net metering adoption. A national study estimated that 200 MW of the technical potential for the assessment period is linked to small-scale solar PV installations, so this figure is reduced by 15-20%, resulting in a reduction of 37–50 MW.
- Lack of clear regulations – Minus 5–10% (general level), based on how regulatory uncertainty affects investor confidence, as observed in past net metering policy adjustments.
- Complex approval process – Barrier is overcome by other policy interventions to streamline permitting (discussed in step 3).
- High initial capital cost – Minus 10–15% (technology-specific), based on market assessments of upfront solar PV installation costs and financing constraints.
- Public skepticism / low awareness – Minus 5–10% (general level), based on survey data on consumer perceptions and adoption trends.

The total effect of barriers is estimated at **35 - 55%** reduction in the net metering policy's technical potential. Final adjusted range for expected renewable energy generation under net metering **90-130 MW** (out of an initial 200 MW).

90–130 MW

Box 5.C13. VRE integration with grid- battery storage (example 4) – accounting for other barriers to refine expected RE addition

1. Estimate technical potential for the assessment period - 1300 MW

2. Account for policy design characteristics - 800 MW

3. Account for effect on financial feasibility of RE technologies - 600 MW

4. Account for other barriers

In step 1, identify key barriers

The key barriers affecting VRE integration with grid-battery storage policies are:

- **Technical:** Grid integration complexity due to inadequate SCADA/EMS systems (grid control software), making real-time dispatch difficult
- **Regulatory/policy:** Lack of a specific framework to promote or support storage for VRE integration
- **Institutional:** Utilities lack internal skills and dedicated teams to plan and operate storage
- **Market:** No market for ancillary services; batteries cannot earn revenue for services like frequency regulation
- **Infrastructure:** Weak local grids that cannot support rapid charging/discharging
- **Financial:** LCOS, lack of revenue stacking opportunities, and high degradation costs (wear and tear) affecting long-term project returns

In step 2, evaluate severity of barriers (scale 1–5)

- Grid integration complexity – 3 (medium)
- Lack of enabling policy – 4 (high)
- Limited utility capacity – 3 (medium)
- No ancillary services market/revenue stacking – 4 (high)
- Weak grid infrastructure – 3 (medium)
- High LCOS and degradation costs – 4 (high)

In step 3, account for other policies addressing barriers

- **Grid modernization:** Investment in smart grid and SCADA infrastructure
- **Policy road map:** Introduction of national energy storage targets
- **Capacity-building:** Training programmes for utility staff
- **Market reform:** Establishing ancillary services markets to allow revenue stacking

In step 4, consider effect of barriers on technical potential (expert judgement)

- Grid complexity: Reduces potential by 5–10 per cent
- Lack of policy: Reduces potential by 10–15 per cent
- Limited utility capacity: Reduces potential by 5–10 per cent
- Market/financial barriers (including LCOS and revenue stacking): Reduces potential by 15–20 per cent
- Weak infrastructure: Reduces potential by 5–10 per cent

Total estimated reduction: Approximately 40–65 per cent

Final result: Out of an initial 30 MW identified, the expected RE addition is refined to 10.5–18 MW after accounting for technical, market and financial barriers.

10.5–18 MW

Appendix D: Paris agreement crediting mechanism

Appendix 6.D1: Overview of the Paris Agreement Crediting Mechanism combined margin approach

The CM approach employed under the Paris Agreement Crediting Mechanism is governed by the methodological tool for calculating emissions from electricity generation and consumption (A6.4-AMT-007). It provides approaches and options to determine the respective emission factors for electricity generation and consumption in the baseline scenario and/or project scenario.

The emission factor of the electricity system can be determined as the CM emission factor, which is the result of a weighted average of two emission factors pertaining to the electricity system: the OM emission factor and the BM emission factor (see equation D.1). The OM emission factor aims to represent the emissions intensity of existing power units whose electricity generation is affected by the Article 6.4 activity. The BM emission factor aims to represent the average emissions intensity of new power units that would likely be built in the absence of the Article 6.4 activity.

Equation D.1.

Calculating the CM emission factor

$$EF_{CM,t} = EF_{OM,t} \times w_{OM} + EF_{BM,t} \times w_{BM}$$

Where:

$EF_{CM,t}$ = CM CO₂ emission factor in period t (tCO₂/MWh)¹²

$EF_{OM,t}$ = OM CO₂ emission factor in period t (tCO₂/MWh)

$EF_{BM,t}$ = BM CO₂ emission factor in period t (tCO₂/MWh)

w_{OM} = weighting factor of the OM emissions factor (unitless)

w_{BM} = weighting factor of the BM emissions factor (unitless)

t = period for which the emission factor of the electricity system is determined (either the calendar year y of the crediting period or the hour h within the calendar year y of the crediting period)¹³

The default values in Table 6.D1 shall be used for w_{OM} and w_{BM} , unless the mechanism methodology referring to this methodological tool specifies other values.¹⁴ Activity participants shall use the more conservative approach, which results in a higher emission factor for case 1 and a lower emission factor for case 2, between (i) using the lower value for w_{OM} combined with the upper value for w_{BM} or (ii) using the upper value for w_{OM} combined with the lower value for w_{BM} , such that the sum of w_{OM} and w_{BM} is equal to 1.

In this guide, the electricity system is assumed to correspond to the grid affected by the policy (scenario A). Off-grid generation through captive power plants (scenarios B and C) is not included. Therefore, the guide focuses directly on the calculation steps for the CM, OM and BM emission factors for scenario A only.

Figure 6.D1 outlines the sequence of steps for sources that fall under scenario A. Steps 1, 2, and 3 are identifying the relevant electricity generation and consumption sources, confirming that scenario A, i.e., the electricity system, corresponds to the grid affected by the policy. The sections below describe the subsequent steps (step 4 onwards):

12. That is, tonnes of carbon dioxide equivalent per megawatt hour.

13. Note that the BM emission factor is always calculated for a calendar year y. Where the OM emission factor is determined on an hourly basis, the annual value of the BM emission factor may be applied to each hour h.

14. Mechanism methodologies may, for example, specify more narrow ranges of the values for specific technologies or circumstances, such as different ranges for different types of renewable power generation technologies (e.g., wind power, solar PV) or different circumstances (e.g., availability of solar radiation or the share of renewable electricity generation).

Table 6.D1. Default values for w_{OM} and w_{BM} ¹⁵

Type of electricity generation or consumption source	w_{OM}		w_{BM}	
	Lower value	Upper value	Lower value	Upper value
- Intermittent electricity generation sources - Electricity consumption sources depending on intermittent generation	0.25	0.75	0.25	0.75
- Non-intermittent electricity generation sources - Electricity consumption sources not depending on intermittent generation	0.125	0.375	0.625	0.875

Note:

In the full Article 6.4 tool, the methodology begins with identifying the relevant electricity generation and consumption sources. For each, it is determined whether electricity is consumed from or fed into an electricity system, or whether it is consumed from or avoids power generation by a fossil fuel-fired captive power plant, using the following scenarios:

- Scenario A: Electricity is consumed from or fed into an electricity system only.
- Scenario B: Electricity is consumed from or avoids power generation by a fossil fuel-fired captive power plant only.
- Scenario C: This is a combination of scenarios A and B, wherein the electricity is consumed from or fed into an electricity system and is consumed from or avoids power generation by a fossil fuel-fired captive power plant.

Step 4: Determine whether applying a higher or a lower value for emissions from electricity generation is more conservative

This step (under scenario A and starting with step 4 of figure 6.D1) serves to determine whether applying a higher or a lower value for emissions from electricity generation represents the more conservative approach. For this purpose, this methodological tool defines two cases:

- Case 1: This considers situations in which a higher value for emissions from electricity generation is more conservative. This case applies to the determination of the parameters related to project emissions

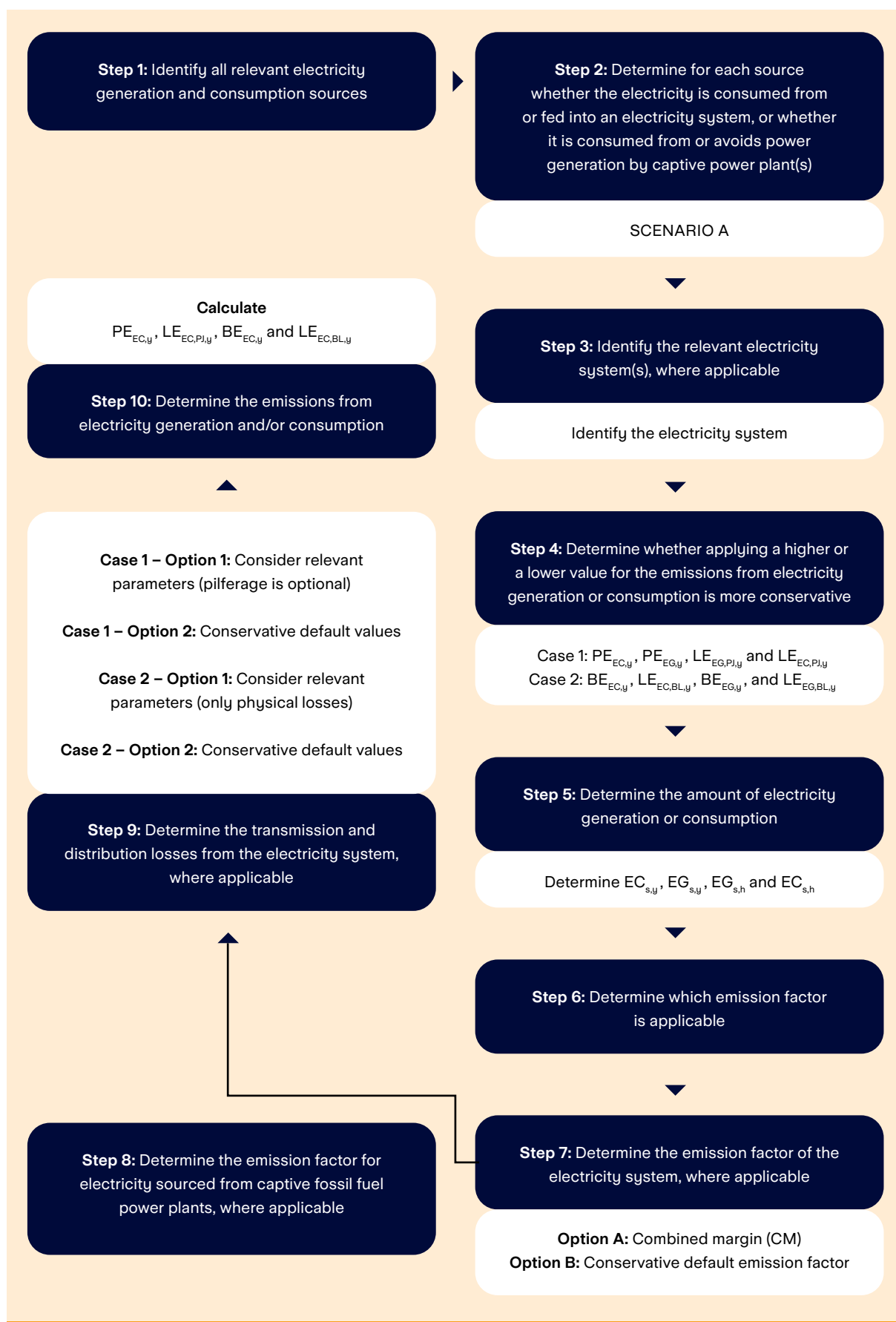
from electricity generation in year y ($PE_{EG,y}$) and leakage emissions from electricity generation in the project scenario in year y ($LE_{EG,P,y}$).

- Case 2: This considers situations in which a lower value for emissions from electricity generation is more conservative. This case applies to the determination of the parameters relating to baseline emissions from electricity generation in year y ($BE_{EG,y}$) and leakage emissions from electricity generation in the baseline scenario in year y ($LE_{EG,BL,y}$).

Activity participants shall determine and justify, for each electricity generation source(s),

15. These values are based on an expert judgement by the Article 6.4 Methodological Expert Panel, which is informed by an assessment of the 'capacity value' of different types of power units based on the literature. The capacity value reflects the contribution that a generation resource makes to grid reliability. Here, it is assumed that non-intermittent power units have a higher capacity value and therefore have a stronger effect on the BM emission factor.

Figure 6.D1. Flow chart to calculate the emissions from electricity consumption and/or generation for energy sources under scenario A



whether case 1 or case 2 applies. Table 6.D2 provides examples for instances where case 1 and case 2 applies, including for intermittent and non-intermittent electricity generation sources, noting that some instances may apply in very specific circumstances only.

Step 5: Determine the amount of electricity generation and/or consumption

Where case 1 applies, activity participants shall apply the following simplified and conservative options for electricity generation:

- Identify the nominal capacity (in MW) of the respective power plant/unit.
- Multiply the nominal capacity by the actual operating hours of the power plant or by 8,760 hours/year.

Where case 2 applies, activity participants shall – as a simplified and conservative approach – apply a value of zero to the electricity generation of the respective sources.

Step 6: Determine the emission factor of the electricity system, where applicable

The emission factor of the electricity system can be calculated by choosing one of two options:

- Option A: Calculate the CM emission factor of the electricity system.
- Option B: Use a conservative default emission factor.

Option A: Calculate the CM emission factor of the electricity system

The emission factor of the electricity system shall be determined as the CM emission factor, which is the result of a weighted average of two emission factors pertaining to the electricity system: the OM emission factor and the BM emission factor. The OM emission factor aims to represent the emissions intensity of existing power units whose electricity generation is affected by the policy. The BM emission factor aims to represent the average emissions intensity of new power units that would likely be built in the absence of the policy. For both cases 1 and 2, the emission factor of the electricity system shall be determined in the same way.

The OM emission factor (EFOM,t) shall be determined based on one of four methods:¹⁶

1. **Dispatch data OM:** The dispatch data OM emission factor (EFOM,DD,t) can be determined based on the power units in the electricity system that are dispatched at the margin during each hour h in which

Table 6.D2. Examples of activities where case 1 or case 2 applies

	Case 1	Case 2
Non-intermittent electricity generation	Uses electricity from a pre-existing fossil fuel power unit that delivered electricity to the electricity system	Installs a biomass power plant that delivers electricity to the electricity system
Intermittent electricity generation	Uses electricity from a pre-existing renewable power unit that delivered electricity to the electricity system	Installs a wind power plant that delivers electricity to the electricity system

16. The Methodological Expert Panel may consider further methods in the future. In addition, activity participants may also submit proposals for a revision of this tool to include other methods. For example, in some instances an electricity consumption source that depends on intermittent generation may only depend on one form of intermittent generation (e.g., only wind power). The effect of such an instance on the electricity system could be reflected through a more refined method in the future.

the intervention activity is displacing electricity in, or consuming electricity from, the electricity system. Accordingly, the dispatch data OM emission factor shall always be determined ex-post for the relevant monitoring period. It can be calculated using one of two approaches:

- i. Based on hourly fuel consumption data, where available, as in equation D.2.

Equation D.2.

Hourly fuel consumption data

$$EF_{OM,DD,h} = \frac{\sum_{i,p} FC_{i,p,h} \times NCV_{i,t} \times EF_{CO_2,i,t}}{\sum_p EG_{p,h}}$$

Where:

$EF_{OM,DD,h}$ = Dispatch data OM emission factor during hour h within period t (tCO₂/MWh)

$FC_{i,p,h}$ = Amount of fuel type i consumed by power unit p in hour h (mass or volume unit)

$NCV_{i,t}$ = Net calorific value (energy content) of fuel type i in period t (GJ/mass or volume unit)

$EF_{CO_2,i,t}$ = CO₂ emission factor of fuel type i in period t (tCO₂/GJ)

$EG_{p,h}$ = Net electricity generated and delivered by power unit p to the electricity system in hour h (MWh)

p = Power units in the electricity system that operate within the top of the dispatch order in hour h

i = Fuel types combusted in power unit p in period t

h = Hours in period t in which the Article 6.4 activity is displacing electricity in, or consuming electricity from, the electricity system

t = Timeframe used to quantify emissions from consuming electricity from, or displacing electricity to, the power grid

- ii. Based on the net electricity generation of each power unit p and a CO₂ emission factor for each power unit p, as in equation D.3.

Equation D.3.

Dispatch data OM from net electricity generation

$$EF_{OM,DD,h} = \frac{\sum_p EG_{p,h} \times EF_{EL,p,t}}{\sum_p EG_{p,h}}$$

Where:

$EF_{OM,DD,h}$ = Dispatch data OM emission factor during hour h within period t (tCO₂/MWh)

$EG_{p,h}$ = Net electricity generated and delivered by power unit p to the electricity system in hour h (MWh)

$EF_{EL,p,t}$ = CO₂ emission factor of power unit p in period t (tCO₂/MWh)

p = Power units in the electricity system that operate within the top of the dispatch order in hour h

h = Hours in period t in which the Article 6.4 activity is displacing electricity in, or consuming electricity from, the electricity system

t = Timeframe used to quantify emissions from consuming electricity from, or displacing electricity to, the power grid.

2. **Simple OM:** The simple OM emission factor ($EF_{OM,simple,y}$) can be determined as the generation-weighted average CO₂ emission factor per unit of net electricity generation from all power units serving the electricity system that are not designated as must-run power units. It can be calculated using one of two approaches:

- a. Based on the net electricity generation of each power unit not designated as a must-run power unit and a CO₂ emission factor for that power unit, as in equation D.4.

Equation D.4.

Simple OM from net electricity generation

$$EF_{OM,simple,t} = \frac{\sum_p EG_{p,t} \times EF_{EL,p,t}}{\sum_p EG_{p,t}}$$

Where:

$EF_{OM,simple,t}$ = Simple OM CO₂ emission factor in period t (tCO₂/MWh)

$EG_{p,t}$ = Net quantity of electricity generated and delivered to the electricity system by power unit p in period t (MWh)

$EF_{EL,p}$ = CO₂ emission factor of power unit p in period t (tCO₂/MWh)

p = Power units not designated as must-run power units delivering electricity to the electricity system in period t

t = Relevant period (under the ex-ante option, the most recent three historical calendar years for which data are available; under the ex-post option, the historical year)

- b. Based on the total net electricity generation of all power units serving the electricity system that are not designated as must-run power units and the fuel types and total fuel consumption of these power units. This approach shall only be used if:

- The necessary data for approach 2.1 are not available.
- Only nuclear and renewable power generation units are designated as must-run power units.

The quantity of electricity supplied to the electricity system by these power units is known.

This would be calculated as in equation D.5.

Equation D.5.

Simple OM from fuel consumption data

$$EF_{OM,simple,t} = \frac{\sum_i FC_{i,t} \times NCV_{i,t} \times EF_{CO2,i,t}}{EG_t}$$

Where:

$EF_{OM,simple,t}$ = Simple OM CO₂ emission factor in period t (tCO₂/MWh)

$FC_{i,t}$ = Amount of fuel type i consumed by power units that are not designated as must-run power units in period t (mass or volume unit)

$NCV_{i,t}$ = Net calorific value (energy content) of fuel type i in period t (GJ/mass or volume unit)

$EF_{CO2,i,t}$ = CO₂ emission factor of fuel type i in period t (tCO₂/GJ)

EG_t = Net electricity generated and delivered to the electricity system by all power units serving the electricity system that are not designated as must-run power units in period t (MWh)

i = All fuel types combusted in power units serving the electricity system that are not designated as must-run power units in period t

t = Relevant period (under the ex-ante option, the most recent three historical calendar years for which data are available; under the ex-post option, the historical year).

Under the ex-ante option or where a historical year v is used under the ex-post option, the simple OM emission factor derived from historical data shall be adjusted to account for the data vintage. Here, it should be noted that, in many electricity systems, the average emissions intensity of existing power units declines over time due to an increasing share of RE power units, the use of more efficient power units, and the use of less GHG-intensive fuels, as in equation D.6.

Equation D.6.

Simple OM adjusted for data vintage

$$EF_{OM, simple, y} = EF_{OM, simple, t} \times [1 - F_{OM, simple} \times (y - t)]$$

Where:

$EF_{OM, simple, y}$ = Simple OM CO₂ emission factor in year y (tCO₂/MWh)

$EF_{OM, simple, t}$ = Simple OM CO₂ emission factor in period t (tCO₂/MWh)

$F_{OM, simple}$ = Factor accounting for the likely annual decrease of the simple OM emission factor over time

y = Calendar year of the crediting period for which emission reductions are determined

t = Period for which the simple OM emission factor is calculated (under the ex-post option, the historical year v; under the ex-ante option, the central calendar year of the three-year period used to calculate the emission factor)

3. Simple adjusted OM ($EF_{OM, adj, t}$):

This is a variation of the simple OM, with an adjustment for periods in which either (i) renewable electricity generation is curtailed because available output exceeded what the electricity system could absorb, or (ii) the electricity system operates solely based on renewable, nuclear and/or storage power units. Here, there are two options:

- a. Based on (i) hourly data on the electricity generation or consumption from all sources, (ii) hourly data indicating whether renewable electricity generation is curtailed because available output exceeded what the electricity system could absorb, (iii) hourly indicating whether the electricity system operates solely based on renewable, nuclear, and/or storage power units, and (iv) annual data used to calculate the simple OM emission factor; as in equation D.7.

Equation D.7.

Simple adjusted OM from hourly data

$$EF_{OM, adj, h} = S_h \times EF_{OM, simple, y}$$

- b. Based on annual data on electricity generation or consumption from all sources and aggregated information on the number of hours in which the renewable electricity generation is curtailed because available output exceeded what the electricity system could absorb, and/or the electricity system operates solely based on renewable, nuclear, and/or storage power units; as in equation D.8.

Equation D.8.

Simple adjusted OM from annual data

$$EF_{OM, adj, y} = (1 - \lambda_y) \times EF_{OM, simple, y}$$

Where:

$EF_{OM, adj, y}$ = Simple adjusted OM CO₂ emission factor in year y (tCO₂/MWh)

S_h = Binary parameter indicating whether during hour h renewable electricity generation in the electricity system is curtailed because available output exceeded what the electricity system could absorb and/or the electricity system operates solely based on renewable, nuclear, and/or storage power units ($S_h = 0$ for any hour in which either of these conditions applies, and $S_h = 1$ for all other hours)

$EF_{OM, simple, y}$ = Simple OM CO₂ emission factor in year y (tCO₂/MWh)

λ_y = Fraction of time in year y during which renewable electricity generation in the electricity system is curtailed because available output exceeded what the electricity system could absorb and/or the electricity system operates solely based on renewable, nuclear, and/or storage power units

y = Calendar year of the crediting period for which emission reductions are determined

4. Average OM ($EF_{OM, avg, y}$): This can be determined as the generation-weighted average CO₂ emission factor per unit of net electricity generation from all power units in the electricity system. The average OM emission factor ($EF_{OM, avg, y}$) shall be calculated as the generation-weighted average emission factor of all power units

serving the electricity system, using the same approaches as for the simple OM emission factor, but also including power units designated as must-run in all equations. As for the simple OM emission factor, either the ex-ante option or the ex-post option may be used.

As for the BM emission factor ($EF_{BM,y}$), it shall be determined based on the generation-weighted average emissions intensity of new power units that started supplying electricity to the electricity system during a reference period. Where the necessary data are available, the reference period shall reflect the period in which the activity starts operation (hereinafter referred to as the concurrent reference period). Where the relevant data are not available at the time of calculating the BM emission factor, a historical reference period may be used. In the case of a historical reference period, the average emissions intensity of new power units shall be adjusted to account for data vintage, noting that, in many electricity systems, the average emissions intensity of new power units declines over time due to an increasing share of RE power units, the use of more efficient power units, and the use of less GHG-intensive fuels.

For a concurrent reference period, use equation D.9.

Equation D.9.

BM emission factor for a concurrent reference period

$$EF_{BM,y} = \frac{\sum_p EG_{p,t} \times EF_{EL,p,t}}{\sum_p EG_{p,t}}$$

For a historical reference period, use equation D.10.

Equation D.10.

BM emission factor for a historical reference period

$$EF_{BM,y} = \frac{\sum_p EG_{p,t} \times EF_{EL,p,t}}{\sum_p EG_{p,t}} \times [1 - FBM \times (x - r)]$$

Where:

$EF_{BM,y}$ = BM CO₂ emission factor in year y (tCO₂/MWh)

$EG_{p,t}$ = Net quantity of electricity generated and delivered to the electricity system by power unit p in period t (MWh)

$EF_{EL,p,t}$ = CO₂ emission factor of power unit p in period t (tCO₂/MWh)

p = Power units included in the BM

y = Calendar year of the crediting period for which emission reductions are determined

t = Period from the start of the reference period up to the most recent calendar year for which electricity generation data are available¹⁷

F_{BM} = Factor accounting for the likely annual decrease of the BM emission factor over time

x = Calendar year in which the Article 6.4 activity starts operation

r = Central year within the historical reference period (e.g., z-1 for a three-year historical reference period and z-3 for a five-year historical reference period)

z = Most recent calendar year for which data are available on new power units that started supplying electricity to the electricity system

17. For example, the reference period may start on 1 January 2022. If a project determines the emission factor for the year 2029, the most recent available data may be available for 2027. In this case, period t corresponds to the six-year period from 1 January 2022 to 31 December 2027. If a power unit p included in the BM calculation started operation on 1 July 2023, the electricity generation data for that power unit shall cover the period from 1 July 2023 until 31 December 2027. If another power unit p included in the calculation started operation on 15 November 2024, the electricity generation data for that power unit shall cover the period from 15 November 2024 until 31 December 2027.

Option B: Use a conservative default emission factor

Where case 1 applies (see table 6.D2) and the electricity generation source is not intermittent, or the electricity consumption source does not depend on intermittent generation, activity participants shall apply one of the following default emission factors, as applicable:

- 0.44 tCO₂e/MWh: Used if there is high confidence that the share of electricity generation from renewable (excluding solar and wind) and nuclear energy in the electricity system exceeds 67 per cent in the period for which the emission factor is determined.¹⁸
- 0.87 tCO₂e/MWh: Used if there is high confidence that the share of electricity generation from renewable (excluding solar and wind) and nuclear energy in the electricity system exceeds 33 per cent in the period for which the emission factor is determined.
- 1.3 tCO₂e/MWh¹⁹

Where case 2 applies, activity participants shall apply one of the following default emission factors and justify the choice in the PDD project design document or monitoring report, as applicable:

- 0.2 tCO₂e/MWh: Used if there is high confidence that the share of electricity generation from RE (including solar and wind) and nuclear energy in the electricity system is less than 33 per cent in the period for which the emission factor is determined.²⁰
- 0.1 tCO₂e/MWh: Used if there is high confidence that the share of electricity generation from RE (including solar and wind) and nuclear energy in the electricity systems is less than 67 per cent in the period for which the emission factor is determined.²¹

- 0.03 tCO₂e/MWh²²

Used where neither of the above conditions can be demonstrated with high confidence.

Appendix 6.D2: Emission factor modelling

This approach tracks how structural and operational changes in the electricity grid affect emissions over time. It uses historical data from power plants to create statistical models based on key variables such as electricity imports and exports, supply-demand dynamics, and trading patterns.

One example is the AVOIDed Emissions and geneRATION Tool (AVERT) (by the United States Environmental Protection Agency), which uses hourly, unit-level data to estimate avoided emissions from RE and energy efficiency measures. While AVERT can provide hourly emissions patterns, it does not generate real-time emission factors, as it relies on historical data and observed patterns. As a result, it may not fully capture future changes in grid infrastructure, policy or pricing. For example, a wind plant commissioned in 2025 might displace gas-fired generation rather than coal; however, AVERT when based on older historical data (e.g., from 2020) may still assume coal as the marginal generation source. In addition, AVERT is limited to regional grids in the United States of America, and uses only data from the United States of America.

The IEA global database also provides country-level electricity emission factors, but these are similarly based on historical data. Other models, such as WattTime and Cambium (developed by NREL), track emissions in real time; however, they are relatively complex and they are not covered here.

In such cases, projection-based energy models (see section 6.2.1) may be more appropriate.

18. Calculated as 1.3 tCO₂/MWh × 2/3.

19. This value represents a conservative (i.e., higher end) value for the emissions intensity of coal power generation (see table 3).

20. Calculated as 0.3 tCO₂/MWh × 2/3. The value of 0.3 tCO₂/MWh represents a conservative (i.e., lower end) value for the CO₂ emissions intensity of a natural gas power plant (see table 3).

21. Calculated as 0.3 tCO₂/MWh × 1/3.

22. This value is based on upstream emissions from solar PV power plants as reported in NREL (2012).

Appendix E: End to end example

End to end example for ICAT Renewable Energy methodology: Feed-in tariff

This section presents an illustrative application of the renewable energy methodology using a hypothetical feed-in tariff policy considering an ex-ante assessment. It demonstrates, from start to finish, the sequence of steps involved in applying the methodology for explanatory purposes.

While the example focuses on a feed-in tariff policy, the key methodological steps and analytical framework are generally applicable across the five renewable energy policies covered by this methodology. The example is intended to help users understand how the methodology can be applied in practice by demonstrating each stage of the assessment process, from describing the policy and defining key assumptions through to estimating its GHG impacts.

Users should note, however, that the specific application of the methodology in their own context will depend on the design and implementation characteristics of the policy being assessed. Although the overall assessment process remains broadly similar, different policy instruments, and even different feed-in tariff designs, may involve important nuances, assumptions, data requirements, and calculations that need to be considered and reflected in the analysis. Accordingly, users should adapt the example as appropriate to their specific policy context.

Step 1: Define policy to be assessed

In the first step, users are required to clearly describe the policy under assessment. To support the development of a comprehensive policy description, a checklist of essential information is provided (see Table E.1). Table E.1 presents an illustrative example of a feed-in tariff policy description.

Table E.1. Checklist of recommended information to describe the policy being assessed

Information	Feed-in tariff policy characteristics
Title of the policy or action	Feed-in tariff without cap
Type of instrument	Feed-in tariff policy
Description of specific interventions	Policy characteristics: - Tariff differentiation – higher tariffs for small projects and lower tariffs for large-scale projects (set to give rates of return of 5–8%) - Eligibility – the only technology eligible under the feed-in tariff is solar PV - Utility role – government-owned single buyer with guaranteed purchase up to the annual production quota - Payment structure – premium-price policies - Contract and payment duration – premium is offered over a project's entire lifetime

Information	Feed-in tariff policy characteristics
	- Contract and payment duration – premium is offered over a project's entire lifetime - Forecasting – no forecasting requirements - Grid access – grid priority for renewable energies - Policy adjustments – only inflation adjustments over lifetime of feed-in tariff
Status of policy	Implemented
Date of implementation	1 July 2016
Date of completion (if relevant)	No end date has been set
Implementing entity or entities	Ministry of Energy/Energy Regulatory Commission
Objectives and intended impacts or benefits of the policy	To increase deployment of solar PV and increase energy security
Level of the policy	National
Policy inputs	- Government budget allocated to finance feed-in tariff payments - Establishment of a renewable energy unit within the Ministry of Energy - Recruitment and training of regulatory staff to administer the scheme - Development of solar resource maps and grid integration studies
Policy activities	- Issuing feed-in tariff regulations and tariff schedules - Reviewing and approving solar PV project applications - Signing PPAs with project developers - Monitoring electricity generation and compliance with policy requirements
Geographic coverage	Small, least developed country
Sectors affected	Energy supply, grid-connected solar PV

Information	Feed-in tariff policy characteristics
Greenhouse gases affected	Carbon dioxide
Costs	▪ Government spending to cover FIT premium payments. ▪ Administrative costs for running the regulatory unit and managing applications. ▪ Capacity-building expenses for training staff. ▪ Costs for technical studies (e.g., resource mapping, grid studies). ▪ Monitoring and compliance costs for verifying generation and ensuring contract adherence. ▪ Developer transaction costs for permits, documentation, and PPA negotiations under the FIT scheme.
Other related policies or actions	Fossil fuel subsidies, tender policies, tax incentive policies

Step 2: Identify GHG impacts & develop causal chain

GHG impacts are the net changes in greenhouse gas emissions attributable to the implementation of a specific policy. Assessing these impacts involves identifying the policy's intermediate effects, determining the resulting GHG impacts, and developing a policy causal chain that links the policy intervention to its expected outcomes. The following section provides an example for a feed-in tariff policy.

While the identification of intermediate effects and GHG impacts is presented here as a precursor to the development of the causal chain, in practice these analytical steps are often undertaken iteratively and in parallel. This helps ensure that the causal chain accurately reflects the policy's mechanisms of influence and the resulting emission impacts.

2.1 Identify policy intermediate effects

To assess the GHG impacts of a policy, it is important to first understand the mechanisms through which the policy is implemented and influences stakeholder behavior. This involves identifying the key inputs and implementation activities, as well as the resulting intermediate

effects that arise from these actions. Table E.2 provides illustrative example of stakeholder responses to the implementation of a feed-in tariff policy, which can help users identify the intermediate effects associated with policy implementation.

2.2 Identify potential GHG impacts

In this step, it is important to identify all relevant GHG impacts associated with the policy, including positive and negative impacts, intended and unintended effects, impacts occurring within and outside the jurisdiction, and both short-term and long-term effects. Users should also identify the associated emission source categories affected by the policy. Table E.3 provides an illustration of emission source category relevant when assessing the impacts of a feed-in tariff policy.

2.3 Develop a causal chain

A causal chain maps how a policy leads to GHG impacts through a sequence of cause-and-effect relationships. The figure E.1 below illustrates the linkages between the feed-in tariff policy, the anticipated intermediate effects, and the GHG impacts identified in the previous steps.

Table E.2. Stakeholder responses to feed-in tariff policy implementation and intermediate effects

Feed-in tariff policy implementation components	Stakeholder response
Inputs	▪ Access financial incentives such as grants, tax credits, or low-interest loans ▪ Establishment of pilot projects or demonstration sites for renewable energy technologies ▪ Provision of technical assistance and capacity-building programs
Activities	▪ Participate in renewable energy programs and initiatives ▪ Attend training sessions to enhance knowledge of RE technologies and best practices ▪ Invest in renewable energy equipment and infrastructure ▪ Report energy production and consumption data for monitoring purposes
Intermediate effects	▪ Increased interest in, demand for, and manufacturing of renewable energy technologies, as well as increased renewable energy capacity installations and electricity generation). ▪ Decreased costs of renewable energy technologies due to market expansion; reduced investment in and construction of fossil fuel power plants; reduced electricity generation from fossil fuel sources; and potential changes in fossil fuel prices ▪ Changes in the cost of electricity generation and, consequently, electricity prices for consumers ▪ Changes in consumer behavior and electricity consumption patterns in response to evolving electricity prices and the increased availability of renewable energy

Table E.3. GHG source category for feed-in tariff policy

Source category	Description	Emitting entity or equipment	Relevant GHGs
Grid-connected electricity generation	CO ₂ emissions from electricity generation in fossil fuel-fired power plants that are displaced due to the project activity	Grid-connected power plants	CO ₂ , CH ₄ , N ₂ O

Figure E.1. Policy causal chain

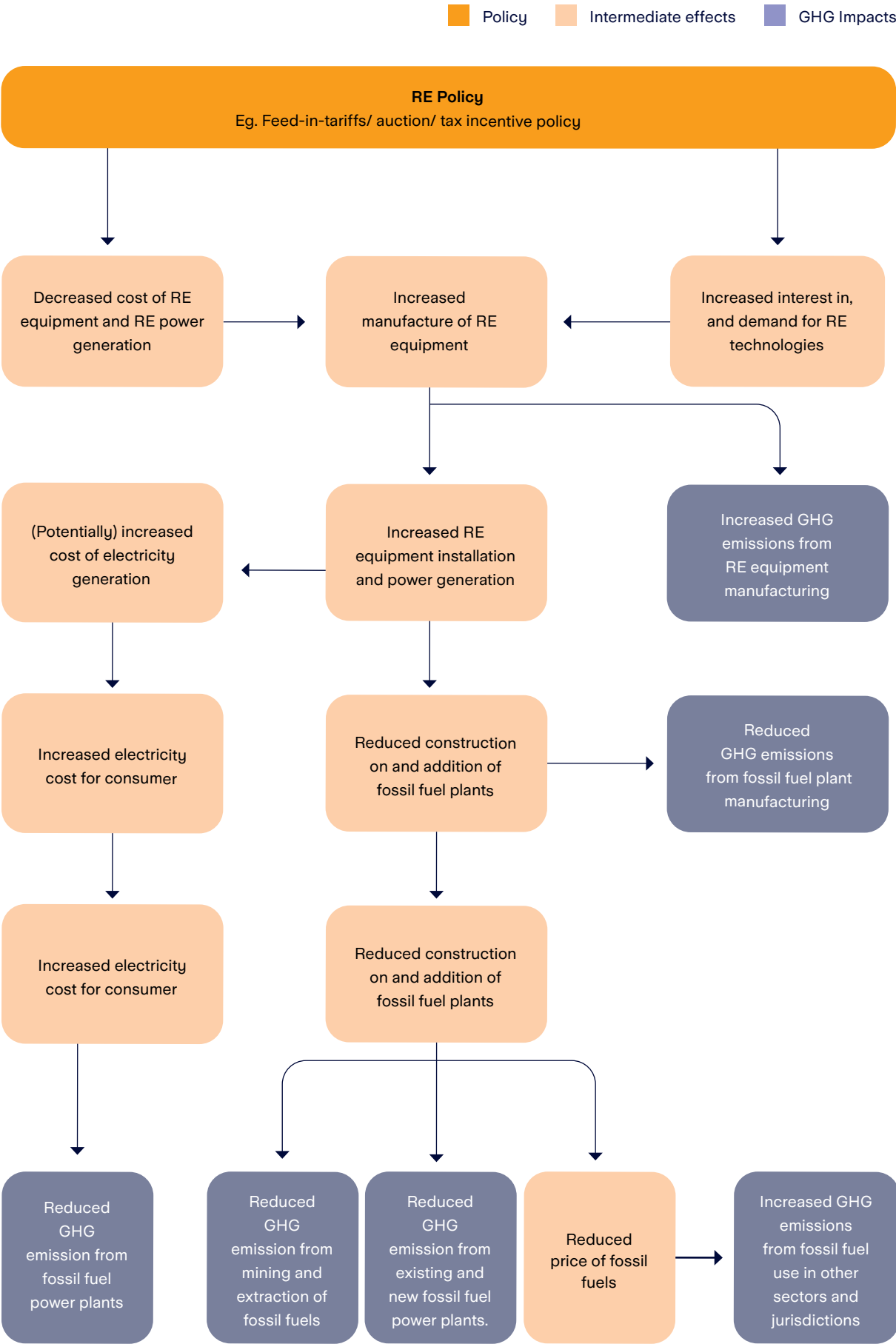


Table E.4. GHG impacts and emission sources considered in defining the GHG assessment boundary for the feed-in tariff policy

wa	Relevant GHGs	Likelihood	Relative magnitude	Included/excluded	Explanation
Reduced GHG emissions from existing and new fossil fuel power plants	CO ₂ , CH ₄ , N ₂ O	Very likely	Major	Included	The main GHG impact of RE policies CO ₂ emissions are major emissions. Other two are minor.
Reduced emissions from mining of fossil fuels (upstream emissions and leakages)	CH ₄ , CO ₂	Possible	Moderate to Major	Excluded	excluding it due to data uncertainty
Induced emissions from RE equipment manufacturing	CO ₂ , CH ₄ , N ₂ O	Possible	Minor	Excluded	These emissions are minor compared to displacement
Reduced emissions from construction of fossil fuel power plants	CO ₂ , CH ₄ , N ₂ O	Possible	Minor	Excluded	Small and typically offsets the emissions from building the new renewable plants.
Increased emissions from fossil fuel used in other sectors and other jurisdictions	CO ₂ , CH ₄ , N ₂ O	Possible	Minor	Excluded	Considered insignificant for this policy
Reduced emissions from fossil fuel power plant operation	CO ₂ , CH ₄ , N ₂ O	Possible	Minor	Excluded	Considered insignificant for this policy

Step 3: Define GHG assessment boundary and period

The GHG assessment boundary defines the scope of GHG impacts included in the assessment. For each identified GHG impact, users are required to assess and rank its likelihood (on a scale ranging from least likely

to very likely) and its magnitude (i.e. minor, moderate, or major). The table below provides an overview of the ranking of the identified GHG impacts for the feed-in tariff policy. The assessment period considered for this example is 15 years.

Step 4: Consider other policy synergies and interactions

When multiple policies are developed or implemented within the same timeframe, users may assess them individually or as part of a policy package. In this example, the feed-in tariff policy interacts with other measures, such as subsidies for power plant equipment, a renewable portfolio standard mandate, and excise duty exemptions on power plant equipment components, as shown in Table E.5.

A preliminary assessment indicates that these interacting policies have only minor to moderate effects on the feed-in tariff policy under evaluation. Furthermore, considering the policy objectives, scope, the feasibility of assessing the measures as a combined package, and the relative level of interaction among them, it is preferable to assess the feed-in tariff policy individually.

Table E.5. Interaction of feed-in tariff policy targeting the same GHG emissions sources as other policies

Policy being assessed	Target emission source(s)	Other policies/ actions targeting the same source	Type of interaction	Degree of interaction
Feed-in-tariff for renewable energy generation	Fossil fuel combustion in grid connected power plants	Subsidy on power plant equipment	Independent	Minor
		Renewable Portfolio Standard (RPS) mandate	Overlapping	Moderate
		Excise duty exemption on power plant equipment parts	Overlapping	Minor

Step 5: Estimating technical potential for the assessment period for a feed-in tariff policy without a policy cap

As the feed-in tariff policy specifies no policy cap for any of the assessment period years, the example follows the approach outlined under Case II: policy without policy cap set for entire assessment period. In this example, a national university with expertise and a progressive energy department produces estimates for the maximum renewable energy resource potential in the country, which they have been updating on a yearly basis for their own research purposes. In a workshop session, the university experts explain their estimates of RE resource potential and the underlying assumptions on all resource and technical factors to ministry representatives.

Both groups jointly conclude that the long-term technical potential for the respective technologies is identified as follows:

- Solar energy – 1,500 MW
- Wind energy – 800 MW

The experts further analyze capacity and, given the trajectory of RE implementation, determine that it is practical to install the following capacities by 2040:

- Solar energy – 900 MW
- Wind energy – 400 MW

Therefore, the overall technical potential of the feed-in tariff policy across technologies for the assessment period by 2030 is determined to be 1,300 MW.

Step 6: Using policy design characteristics to refine expected renewable energy addition for the assessment period

The design characteristics for the feed-in tariff are rated in Table E.6.

As an initial screening step, each policy design characteristic is reviewed to determine whether it is expected to have a material influence on the technical potential during the assessment period. The assessment combines information from the policy design with available evidence, such as national energy expert consultations, investor surveys and project pipeline analysis, to identify those characteristics that warrant quantified adjustments to the technical potential.

The analysis identifies the policy design characteristics that are most likely to affect technical potential as follows:

1. **Eligibility:** The eligibility restriction is expected to directly reduce technical potential, as only solar PV installations are eligible. As a result, the wind energy potential of 400 MW (out of 1,300 MW) is excluded, leaving 900 MW.
2. **Payment structure:** The approach of offering a premium on top of prevailing market prices for electricity is expected to reduce the technical potential for the assessment period, because the partial dependence on the electricity market price introduces a level of uncertainty that

Table E.6. Matrix for rating policy design characteristics

Criterion	Description	Impact	Notes
Eligibility	Limited to solar PV only	Very strong	Restrictive technology scope
Tariff differentiation	Higher tariffs for small projects (5–8% returns target)	Limited	Supports distributed generation
Payment structure	Premium above retail electricity prices	Strong	Provides additional revenue stability
Utility role	Government-owned single buyer with guaranteed purchase	Very strong	Strong revenue certainty
Contract duration	15-year premium payment period	Strong	Adequate for investment recovery
Forecasting requirements	No forecasting obligations	Moderate	Reduces burden but may impact grid planning
Grid access	Priority transmission and dispatch	Very strong	Strong integration support
Policy adjustments	Inflation-only adjustment over lifetime	Moderate	Limited adaptability to market changes

would not exist if the entire feed-in price was fixed. A local consultancy conducted a representative survey of potential power producers and investors (both small scale and large scale) on how this uncertainty might affect future RE deployment. Based on this survey, the local consultants estimate that the uncertainty reduces the technical potential for the assessment period by only about 60 MW (conservative estimate), because most power producers have found ways to deal with the uncertainty (e.g., through integrating it into the rest of their portfolio). This reduces the technical potential for the assessment period to 840 MW.

3. **Utility role:** The government-owned single buyer with guaranteed purchase substantially reduces off-taker risk and provides revenue certainty for investors. Expert consultation concluded that this feature is a key enabler for project development and is reflected in the baseline technical potential estimate. Consequently, no additional adjustment is made.
4. **Contract and payment duration:** The contract and payment duration of 15 years is expected to be too short for several large-scale solar PV projects because power producers would require contracts with payment durations of 20–25 years. A consultation with two local experts on RE investments, which includes a review of the projects currently in the pipeline in the country, reveals that, under these conditions, about 6% of the projects in the pipeline would not be built. This means that the technical potential for the assessment period would be further reduced by 40 MW (conservative estimate) to 800 MW.
5. **Grid access:** Priority transmission and dispatch reduce curtailment risks and improve project viability. Since the initial technical potential assumes that eligible projects can access the grid under the provisions of the policy, no further adjustment is applied.

This assessment identifies eligibility, payment structure and contract duration as the policy design characteristics that require quantitative adjustments to the technical potential for the assessment period. After accounting for these policy design characteristics, the refined technical potential for the assessment period is estimated to be 800 MW (compared to 1,300 MW initially).

Step 7: Using financial factors to refine expected renewable energy

The LCOE calculations for the country revealed costs between 10 cents/kWh and 17 cents/kWh for various locations. Since the solar potential can be roughly divided into four geographic areas, four different representative full load hour estimates were used to estimate these location-specific LCOE costs. The feed-in tariff rate is fixed at 13 cents/kWh. Solar PV will likely be developed in only two of the four geographic areas in which the LCOE is above the wholesale electricity price (i.e. the feed-in tariff rate). As the two regions in which no solar PV will be developed have a total maximum capacity of 100 MW (relatively low as a result of low solar radiation and swampy regions where only limited capacity could be installed), this reduces the technical potential for the assessment period of the policy from 800 MW to 700 MW.

Since both stand-alone and rooftop installations are eligible under the feed-in tariff, financial factors should not further reduce the technical potential for the assessment period in the two geographic areas with higher solar potential, as both areas have meaningful electricity loads and ample space available to build the plants.

The feed-in tariff provides a large degree of certainty to the investor, thereby attracting financing even from risk-averse sources. However, access to finance in general is limited in the country. Even with the guarantee provided by the feed-in tariff, the number of investors will be small. Therefore, after consultation with financial experts in the country, the technical potential for the

assessment period is further refined from 700 MW to 600 MW.

Step 8: Accounting for other barriers to refine expected renewable energy

In this step, firstly the main barriers for the feed-in tariff are identified using the list of barrier categories described in the methodology:

- Technical – no technical standard for rooftop solar PV installations, which has resulted in no domestic technology providers for rooftop solar PV installations
- Regulatory and policy uncertainty – history of numerous ad hoc policy changes and adjustments, leading to a general lack of transparency and uncertainty for market actors
- Institutional and administrative – permits for new RE plants are difficult to obtain because approval procedures are lengthy, non-transparent, and cumbersome
- Market – existing fossil fuel subsidies for low- and medium-income households
- Financial and budgetary – concerns about the financial solvency of only state-owned utilities, with a history of defaults
- Infrastructure – none
- Lack of skilled personnel – lack of skilled personnel to install solar PV panels
- Public acceptance and environmental – none

Next, the severity of each identified barrier is evaluated and rated on a scale of 1 to 5, with 5 indicating very severe:

- No technical standard and no domestic technology providers for rooftop PV installations – 5 (very severe)
- Policy uncertainty due to a history of ad hoc policy changes and adjustments – 2 (low to medium)
- Slow and non-transparent permit approval process – 3 (medium)

- Existing fossil fuel subsidies for low- and medium-income households – 1 (low)
- Concerns about financial solvency of only state-owned utilities with a history of defaults – 3 (medium)
- Lack of skilled personnel to install solar energy panels – 2 (low to medium)

Following the evaluation of barrier severity, other policies are identified that may help the feed-in tariff policy overcome barriers to RE deployment. For example, a separate policy enacted to address the slow and non-transparent permit approval process helps overcome this barrier. The Ministry of Energy is currently carrying out a comprehensive reform of its entire approval processes as a result of new anti-corruption legislation. Thus, the permit approval process will be entirely redesigned to promote a faster and more transparent process. Even though the reform process may require a transitional phase, it is deemed sufficient to overcome the barrier.

Finally, the effect of barriers on the technical potential for the assessment period is estimated. The extent of this effect is based on expert judgment:

- No technical standard and no domestic technology providers for rooftop solar PV panels – This barrier is categorized as very severe (in an earlier step), indicating that few installations can be expected for rooftop solar PV installations under the feed-in tariff policy. A national university has estimated that 50 MW of the 800 MW technical potential for the assessment period of the policy directly links to rooftop installations. This figure is therefore reduced by 50% to 25 MW, which is subtracted from the policy's impact of 600 MW, resulting in 575 MW.
- Policy uncertainty due to history of ad hoc policy changes and adjustments – minus 5–8% (applies to total expected RE addition of the policy for the assessment period), based on the assessment of how policy uncertainty affects investor behavior using survey data from a small representative sample of investors.

- Slow and non-transparent permit approval process – the barrier is overcome by other policy intervention to reform the permit approval process.
- Existing fossil fuel subsidies for low- and medium-income households – minus 3–4% (general level), based on experience with household behavior in the past.
- Concerns about financial solvency of only state-owned utilities with a history of defaults – minus 20–30% (general level), based on the assessment of how policy uncertainty affects investor behavior using survey data from a small representative sample of investors.
- Not enough skilled personnel to install solar energy panels – minus 20% (technology level), based on market assessment of the number of skilled personnel available to install solar energy panels

As the impact of the lack of skilled personnel to install solar PV panels partially overlaps with the impact of no domestic technology providers for rooftop solar PV panels, the barrier-specific impacts cannot be fully aggregated. As the overlap accounts for about 5%, the total effect of the barriers is between 43% and 57%.

The barrier analysis therefore suggests that the feed-in tariff will increase RE generation by between 237 MW and 314 MW. The range represents the uncertainty associated with the identified barriers.

Step 9: Estimate GHG impacts using emission trajectory method ex-ante

This example illustrates the estimation of GHG emission reductions from a feed-in tariff policy using the emissions trajectory method under limited data availability. In situations where data are scarce, users may estimate the impacts of renewable energy policies using appropriate proxy data and simplified analytical approaches.

In this example, the country under assessment does not have projections of future electricity

demand or a baseline emissions scenario. The assessment period extends from the most recent year for which data are available to 2040. For illustrative purposes, the calculations are presented only for the year 2040; however, the same approach can and should be applied to intermediate years throughout the assessment period, as appropriate.

The first step is to estimate the baseline emissions trajectory in the absence of the feed-in tariff policy.

9.1: Project future electricity demand

Future electricity generation can be estimated by taking electricity demand per capita and future population projections as proxies, and assuming transmission and distribution losses.

The first step is to estimate current electricity demand per capita in the country by using current (or last available year) data for total electricity demand and population. Total electricity demand and total population per country can be obtained from international sources (such as the IEA statistics data browser, the Enerdata "Global energy statistical yearbook" World Bank population data or United Nations population data) or national sources (such as ministries of energy, or departments for data and statistics). For most countries, time series of electric power consumption per capita are readily available. For a hypothetical country, electricity demand per capita in 2027 is calculated as follows:

$$\text{EDpCt [kWh/capita]} = \text{TEDt [kWh/year]} / \text{Popt [capita/year]}$$

$$\text{EDpC2017} = (12 \times 10^{10} \text{ kWh/year}_{2017}) / (40 \times 10^6 \text{ capita}_{2017}) = 3,000 \text{ kWh/capita}$$

where EDpC is electricity demand per capita, TED is total electricity demand, Pop is total population and t is the year.

For future years, a range can be estimated by using the following assumptions:

- Electricity demand per capita will remain constant (one end of the range).
- Historical trends will continue in the future (other end of the range).

If historical data indicate that electricity demand per capita in a country has significantly increased or decreased in the past years, it is preferable to assume a continuation of this trend. To adapt the current ED_{pCt} , first estimate the growth rate of the past years GR_t .

For our hypothetical country, the historical trends and estimated growth rates are

provided in Table E.7 below:

The compound annual growth rate (GR_t) is estimated using the following formula:

$$GR_{t_2-t_1} = [(ED_{pCt_2} / ED_{pCt_1})^{1/(t_2-t_1)} - 1] \times 100$$

The compound annual growth rate between 2015 and 2020 is:

Table E.7. Growth rates historical trends

t (year)	2015	2020	2025	2027
ED_{pCt} (kWh/capita)	2,300	2,600	2,900	3,000
GR_t (%/year)		2.48		2.24

$$GR_{2005-2010} = [(2,600 \text{ [kWh/capita]}_{2010} / 2,300 \text{ [kWh/capita]}_{2005})^{1/(2010-2005)} - 1] \times 100 = 2.48\%$$

The average growth rate for the entire period (between 2005 and 2017) is then

$$GR_{2005-2017} = [(3,000 \text{ [kWh/capita]}_{2017} / 2,300 \text{ [kWh/capita]}_{2005})^{1/(2017-2005)} - 1] \times 100 = 2.24\%$$

Energy sector experts from national universities are consulted, and the consensus is that energy demand is likely to grow at 2.2% per year.

To estimate the future emissions, we multiply the ED_{pC} range by the projected population (Pop). World population prospects are available from the United Nations up to 2100. The population in our country is expected to increase from 40 million in 2027 to 45 million in 2040. Thus, the future total electricity demand (TED) range in 2040 is estimated as follows:

- Lower end – assuming electricity demand per capita will remain constant

$$TED_{2040min} = 3,000 \text{ [kWh/capita]}_{2020} \times 45 \times 10^6 \text{ capita} \times 1 \text{ GWh}/10^6 \text{ kWh} = 135,000 \text{ GWh}$$

- Upper end – assuming electricity demand per capita will continue increasing with the same growth rate as in the past

$$ED_{pC2040} = ED_{pC2027} \times (1 + GR_{2015-2027})^{(2040-2027)}$$

$$ED_{pC2040} = 3,000 \text{ [kWh/capita]}_{2027} \times (1 + 2.2\%)^{13} = 4,002 \text{ [kWh/capita]}_{2040}$$

$$TED_{2040max} = 4,002 \text{ [kWh/capita]}_{2040} \times 45 \times 10^6 \text{ capita} \times 1 \text{ GWh}/10^6 \text{ kWh} = 180,074 \text{ GWh}$$

9.2: Project future electricity generation

Future electricity generation is the sum of electricity demand, transmission and distribution (T&D) losses, and own use of electricity by generators.

For our hypothetical country, we will assume 6.2% T&D loss and 5% of own use. To estimate total electricity generation (TEG), we simply apply the following equation:

$$TEG_{2040min} = TED_{2040min} / (1 - T\&Dloss[\%] - OwnUse[\%]) = 135,000 \text{ GWh} / (1 - 11.2\%) = 152,027 \text{ GWh}$$

$$TEG_{2040max} = TED_{2040max} / (1 - T\&Dloss[\%] - OwnUse[\%]) = 180,074 \text{ GWh} / (1 - 11.2\%) = 202,786 \text{ GWh}$$

9.3: Estimate the development of technologies in electricity mix

The next step is to break down total electricity generation into generation technologies. To estimate the future energy mix, one can use the current energy mix (or that of the last available year). This

information can be obtained from national sources (e.g. ministry or department of energy) and international sources.

For our hypothetical country, the electricity generation mix in 2027 is provided in Table E.8 below:

Table E.8. Electricity generation mix 2027

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Share (%)	17	10	40	5	10	10	5	3	0

For the future electricity mix up to 2040, we will consider the following factors:

In our hypothetical country:

- no investment has been made in biomass, oil or geothermal electricity generation in the past 5 years; for nuclear, no investment has been made in the past 20 years
- the current generation technologies under construction include gas, solar PV and wind
- we know (from the national resources database) that there is potential for solar PV, geothermal, wind and hydropower generation
- subsidies exist for oil, coal and gas generation
- historical costs for oil, gas and coal have been continuously increasing in the past 20 years. Future projections from international

sources indicate that prices will continue to increase in the near future.

Based on the information above, we can assume that no new nuclear power plant will be built between 2027 and 2040 (thus, the share for nuclear will slightly decrease); the share for coal, oil, biomass or geothermal will likely not increase (it might slightly decrease); electricity generation from solar PV, wind and gas will slightly increase; and hydropower generation could remain steady or even increase, as there is still potential in the country.

Therefore, we assume the following share for 2040 as seen in Table E.9:

Finally, the electricity generation per technology in 2040 (baseline) is estimated by multiplying the technology share (%) by the estimated TEG range (GWh/year) as seen in Table E.10:

Table E.9. Electricity generation mix 2040

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Share (%)	15	10	42	3	10	12	6	2	0

Table E.10. Electricity generation by technology (baseline)

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Min (GWh/year)	22,804	15,203	63,851	4,561	15,203	18,243	9,122	3,041	0
Max (GWh/year)	30,418	20,279	85,170	6,084	20,279	24,334	12,167	4,056	0

9.4: Calculate emissions levels based on technology-specific emission factors

To estimate the absolute emissions from the baseline scenario emission trajectory, we apply emission factors (EF) per technology

to the estimated total electricity generation per technology. We also consider intensity improvements for these factors.

The emission factors per technology assumed are provided in Table E.11:

Table E.11. Emission factors per technology

Technology	Coal	Oil	Gas
EF (tCO ₂ /MWh)	0.97	0.88	0.45

We can assume that, as a result of plant retrofit and additional capacity of power plants with better technology, these emission factors will

improve by 1% for coal and by 8% for gas, leading to the following emission factors (Table E.12):

Table E.12. Emission factors adjusted considering technology improvements

Technology	Coal	Oil	Gas
EF (tCO ₂ /MWh)	0.96	0.88	0.414

We then multiply emission factors per technology by the projected electricity generation per technology. We then

estimate absolute emissions from electricity generation as the sum of emissions from all technologies (E.13):

Table E.13. Absolute emissions from electricity generation (baseline)

Technology	Coal	Oil	Gas	Total
Min (MtCO ₂ /year)	21.9	13.4	26.4	61.7
Max (MtCO ₂ /year)	29.2	17.8	35.3	82.3

Thus, the emissions levels from the baseline scenario emissions trajectory in 2040 are between 61.7 MtCO₂ /year and 82.3 MtCO₂ /year.

9.5: Estimate policy scenario emissions

We now take into account the implementation of feed-in tariff policy.

The country has decided to focus on its solar potential to transition to a low-carbon power sector by 2040. To this end, an uncapped

feed-in tariff policy for solar power has been implemented to promote uptake of solar power. In a first step, users estimate the technical potential for the assessment period of the policy as 1,300 MW (total RE potential, of which 900 MW is solar power). Assessment of the policy design characteristics therefore reduces this potential to 800 MW (the solar portion). Financial factors and the barrier analysis further reduce the policy's impact to 237–314 MW. This translates to generation of

375–497 GWh/year in 2040, assuming annual average operation of 330 days per year at an average annual capacity factor of 20% for solar for the country. We estimate the specific yield for solar PV in terms of the capacity factor as:

Specific yield_{solar PV} = annual capacity factor × annual average operation

Specific yield_{solar PV} = 0.2 × 330 days/year × 24 h/day = 1,584 MWh/year/MW

We can then estimate the range of electricity generation potential (EG) from introducing the feed-in tariff for solar PV policy as:

$EG_{\min 2040} = 237\text{MW} \times 1,584 \text{ MWh/year/MW} = 375\text{GWh/year}$

$EG_{\max 2040} = 314\text{MW} \times 1,584 \text{ MWh/year/MW} = 497\text{GWh/year}$

Now, we need to re-examine the future electricity mix by taking into account factors such as the interaction of other policies, the country's electricity system type, and changes needed for the system to accommodate higher shares of VRE. After examination of these parameters in the country, we then assume that the solar PV generation originated from the feed-in tariff will replace coal generation.

Implementation of the solar PV feed-in tariff policy would increase VRE share to 20% in 2040, meaning that flexibility in the system would become very important. The country:

- Has an electricity system that is interconnected to neighboring countries' electricity systems
- Has implemented policies for energy demand reduction (e.g. energy efficiency)

Therefore, other than additional transmission and distribution infrastructure, the country's system can accommodate the VRE addition without the need for further changes. Thus, the final generation per technology in 2040 is provided in Table E.14 below:

The next step is to estimate the emissions levels for the policy scenario emissions trajectory.

Users can estimate the absolute emissions from the policy scenario emissions trajectory by applying emission factors per technology to the estimated total electricity generation per technology, while considering intensity improvements for these factors. Using the same assumptions as before for emission factors per technology and improvements in technologies over time, the absolute emissions from electricity generation are estimated as the sum of emissions from all technologies.

Thus, the emissions levels from the policy scenario emissions trajectory are 61.3–81.8 MtCO₂/year.

9.6. Estimate GHG reductions from RE policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory

Finally, the GHG reductions in 2040 from the RE policy (EmRed) are estimated by subtracting the estimated emissions in the policy scenario from the estimated emissions in the baseline scenario:

$EmRed_{\min 2040} = 61.7 \text{ MtCO}_2/\text{year} - 61.3 \text{ MtCO}_2/\text{year} = 0.4 \text{ MtCO}_2/\text{year}$

$EmRed_{\max 2040} = 82.3 \text{ MtCO}_2/\text{year} - 81.8 \text{ MtCO}_2/\text{year} = 0.5 \text{ MtCO}_2/\text{year}$

Table E.14. Final generation per technology in 2040

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Min (GWh/year)	22,429	15,203	63,851	4,561	15,203	18,619	9,122	3,041	0
Max (GWh/year)	29,921	20,279	85,170	6,084	20,279	24,832	12,167	4,056	0

Table E.15. Absolute emissions from electricity generation (policy scenario)

Technology	Coal	Oil	Gas	Total
Min (MtCO ₂ /year)	21.5	13.4	26.4	61.3
Max (MtCO ₂ /year)	28.7	17.8	35.3	81.8

Photo by Mortiz Lange from Unsplash

Resources

Templates

The guide provides users with downloadable templates to support each step of the assessment process, as well as for compiling and reporting results. These templates can also be used for reporting under the UNFCCC. Where applicable, these templates should be revised to align with the requirements of the MPGs.

The available templates include: a policy description template; templates for policy inputs, activities and intermediate effects; a policy GHG impacts template; a policy causal chain template; an assessment boundary template; and an assessment reporting template.

The templates can be accessed using the following link:

<https://climateactiontransparency.org/icat-toolbox/assessment-guides/renewable-energy>

Toolkit

The guide includes reference with links to several tools that users may need for the assessment. The most commonly used modelling tools for technical assessment have been presented in chapter 6.3. Some of the tools are also included in the appendices (e.g., LCOE tool).

The assessment toolkit comprises a collection of resources designed to support the methodology outlined in this guide. It brings together a range of reference materials, databases, calculation tools and supporting documentation that can be used throughout the assessment process. These resources provide key inputs such as activity data,

emission factors, and analytical tools for estimating GHG emissions and evaluating policy impacts.

The toolkit also includes reference documents that can assist in informing different stages of the assessment. While it contains many of the resources that are most widely used, it is not intended to be a comprehensive inventory of all available tools. Users are encouraged to incorporate additional resources where appropriate, particularly those that are specific to the policy being assessed or the national context. Throughout this guide, these supporting materials are collectively referred to as the assessment toolkit.

1. Introduction to the ICAT Assessment Guides		Reference
Institution:	ICAT	
Purpose:	To provide the overarching framework, core concepts and principles that underpin this guide and all ICAT policy assessment guides.	
Description:	Sets out common definitions, assessment principles, approaches to base-line and policy scenarios, boundary setting, uncertainty, stakeholder participation, and reporting, ensuring consistency and transparency across ICAT assessments.	
Link for access:	https://climateactiontransparency.org/icat-toolbox/assessment-guides/introduction-to-the-icat-assessment-guides	

2. Greenhouse Gas Protocol Policy and Action Standard

Reference

Institution: WRI (Rich et al., 2014)**Purpose:** To provide additional details on various components of the assessment process.

Description: Offers a standardized approach for estimating and reporting the change in GHG emissions and removals resulting from the implementation of policies and actions;

complemented by additional sector-specific guidance documents (e.g., energy supply) that provide more detailed methodological approaches for particular sectors.

Link for access: <https://ghgprotocol.org/policy-and-action-standard>

3. Levelized Cost of Electricity Tool

Tool

Institution: Various (e.g., IRENA, IEA, national institutions)**Purpose:** To assess the cost competitiveness of RE technologies supported by a policy.

Description: Estimates the average cost per unit of electricity generated over the lifetime of RE projects, accounting for capital costs, operating costs, performance, and financing assumptions; used in this guide to assess financial feasibility of RE technologies.

Link for access: www.irena.org/Data/View-data-by-topic/Costs/Global-LCOE-and-Auction-values

www.iea.org/data-and-statistics/data-tools/levelised-cost-of-electricity-calculator

www.nlr.gov/analysis/tech-lcoe

4. Global Atlas for Renewable Energy

Tool

Database

Institution: IRENA**Purpose:** To support estimation of RE technical potential.

Description: Provides geospatial data and resource maps for solar, wind, hydro, and other RE sources; referenced in this guide as a source for estimating long-term RE potential.

Link for access: <https://globalatlas.irena.org>

5. Renewables Global Status Report

Database

Institution: REN21**Purpose:** To provide contextual information on RE policies and trends.**Description:** Compiles global and regional data on RE deployment, policies and markets; referenced in this guide for benchmarking and contextual analysis.**Link for access:** www.ren21.net/reports/global-status-report

6. Renewable energy cost and performance statistics

Database

Institution: IRENA**Purpose:** To provide cost and performance data for RE technologies.**Description:** Provides country- and technology-specific data on RE costs, performance and trends; supporting LCOE and financial feasibility analysis.**Link for access:** www.irena.org/Data

7. Methodological tool: Emissions from electricity generation and consumption

Reference

Tool

Institution: UNFCCC, under Article 6.4 mechanism**Purpose:** To provide a standardized methodology for quantifying GHG emissions from electricity generation and consumption, including establishing GEFs.**Description:** Supports the calculation of emissions associated with electricity systems, enabling consistent accounting for emission reductions from power generation and consumption activities under carbon market mechanisms.**Link for access:** <https://unfccc.int/sites/default/files/resource/A6.4-AMT-007-v01.0.pdf>

8. Methodological tool: Investment analysis consumption

Reference

Tool

Institution: UNFCCC, under Article 6.4 mechanism

Purpose: To provide a standardized approach for conducting investment analysis to demonstrate the financial viability and additionality of mitigation activities under the Article 6.4 mechanism.

Description: Outlines methods such as cost analysis, benchmark analysis and investment comparison to assess whether a project is financially attractive without carbon revenues, supporting the demonstration of additionality in carbon market projects.

Link for access: <https://unfccc.int/sites/default/files/resource/A6.4-MEP008-A01.pdf>

9. Article 6.4 Sustainable Development Tool

Tool

Institution: UNFCCC, under Article 6.4 mechanism

Purpose: To ensure that Article 6.4 activities contribute to sustainable development, while identifying, assessing, and managing environmental and social risks.

Description: Provides a structured framework for assessing and monitoring the sustainable development impacts of projects, including applying safeguards, mitigating risks and tracking contributions to the Sustainable Development Goals (SDGs).

Link for access: <https://unfccc.int/sites/default/files/resource/A6.4-TOOL-AC-001.pdf>

10. Derisking Renewable Energy Investment (DREI)

Reference

Institution: UNDP

Purpose: To support policymakers in developing targeted packages of public interventions that address the barriers and risks holding back private-sector investment in renewable energy, by providing a framework to systematically identify and assess these barriers and associated risks.

Description: Introduces an innovative, quantitative framework to assist policymakers in developing countries to cost-effectively promote and scale-up private sector investment in renewable energy.

Link for access: <https://www.undp.org/energy/derisking-renewable-energy-investment-framework>

11. Greenhouse Gas Abatement Cost Model (GACMO)

Tool

Institution: UNEP Copenhagen Climate Centre (UNEP CCC)

Purpose: To support countries to carry out rapid but accurate scenario analysis of how a variety of mitigation options impact emissions, thereby increasing transparency and contributing to informed decision making.

Description: Provides valuable input for preparing and updating NDCs by identifying NDC targets for emissions reductions and by providing assessments of future emissions in different climate action scenarios. It can also be used to prepare biennial transparency reports (BTRs) under the Paris Agreement.

Link for access: <https://unepccc.org/gacmo-tool/>

12. Mechanism Methodology: Electricity generation from renewable sources connected to an electricity system

Reference

Tool

Institution: UNFCCC

Purpose: To define requirements for Article 6.4 activities that involve installation of a greenfield power plant that generates electricity from renewable sources and feeds all electricity generated into an electricity system.

Description: Supports estimation of the GHG emission reductions from renewable electricity generation connected to an electricity system, by determining the grid emissions displaced by the renewable electricity generated. It provides a consistent approach for establishing the baseline and calculating the applicable grid emission factor.

Link for access: <https://unfccc.int/sites/default/files/resource/A6.4-MEP012-A03.pdf>

Photo by John Rae from @UNOPS

Case Studies

This section provides a summary of the experiences from previous applications of the guide in Eswatini and India. It includes an overview of the country context, the objectives of the assessments, descriptions of the policies, GHG mitigation effects,

methodological considerations, the development of causal chains, baseline and policy scenarios, as well as lessons learned. Additionally, it highlights the sustainable development impacts (relating to the SDGs) of the policies.

Eswatini: Assessing the GHG impacts of the policy on renewable energy resources for electricity generation



Photo by Ashim D'Silva from Unsplash

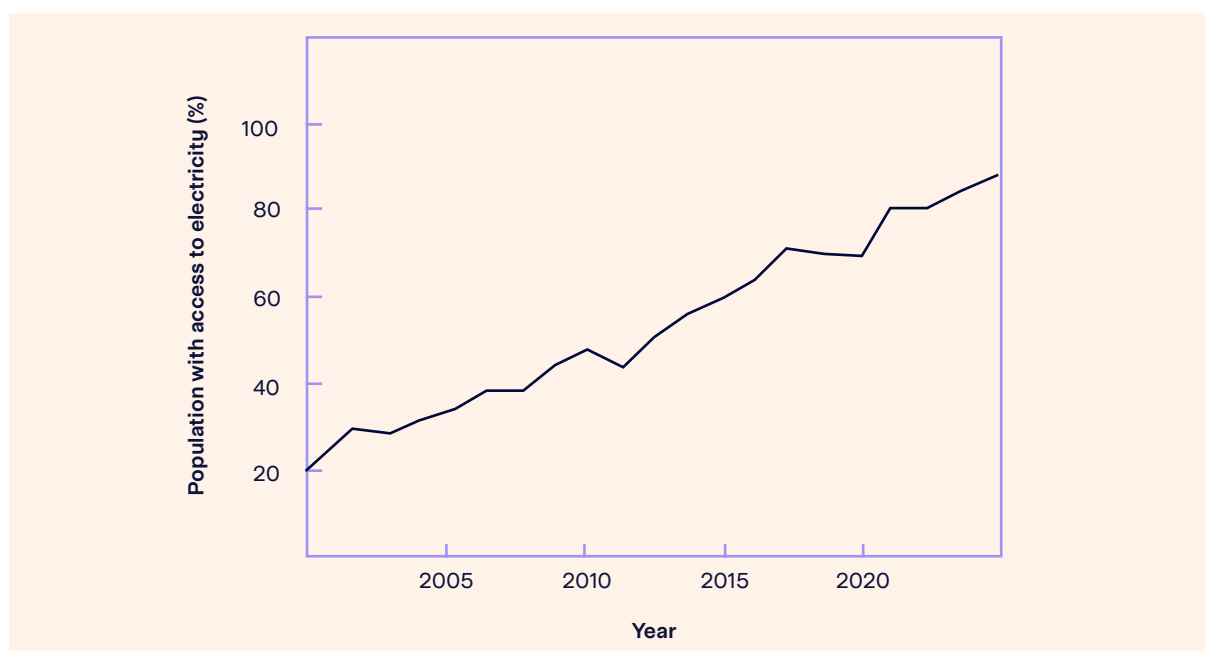
Country context

The Kingdom of Eswatini is classified as a lower-middle-income country, with a GDP per capita of US\$3,797 and an annual GDP growth rate of 4.8 per cent in 2023 (World Bank Group). According to Doing Business 2020 published by the World Bank Group, Eswatini ranked 121st out of 190 countries, suggesting that its regulations provide a moderate level of support for launching new businesses and maintaining existing operations (World Bank Group, 2019).

Electricity access among the population of Eswatini has increased consistently over the last 20 years, rising from 20.4 per cent in 2000 to 82.3 per cent in 2023, as illustrated in figure

CS.1. In 2022, the country's per capita GHG emissions stood at 1.3 tCO₂e, which is lower than both the African average of 3.3 tCO₂e and the global average of 6.8 tCO₂e (Ritchie, Rosado and Roser, 2023).

Eswatini's carbon footprint remains comparatively low, though this is partly due to the country importing approximately 70 per cent of its electricity needs from South Africa, Mozambique and the Southern African Power Pool. The remaining 30 per cent produced domestically comes from RE sources. The country does operate some small-scale fossil fuel power plants for dedicated use, including a 2MW coal-fired facility. According to the most recent GHG inventory, emissions from

Figure CS.1. Share of the Eswatini population with access to electricity

electricity and heat production (using fossil fuels) totalled 90,000 MtCO₂e, significantly below the agriculture sector's 990,000 tCO₂e and transport sector's 730,000 tCO₂e. Nevertheless, emissions from the electricity sector are expected to rise as Eswatini works to boost domestic power generation to ensure energy security.

The National Energy Policy (NEP) of 2018, which is based on the vision “To meet the energy needs of the country in a sustainable manner that contributes to economic growth and well-being of the population”, has several positions addressing the generation of electricity and RE, which provide the basis for the development of RE resources in the country (Eswatini, Ministry of Natural Resources and Energy, 2018).

Policy assessment objectives

This assessment aims to evaluate the ex-ante impact of Eswatini's RE policy framework on the GHG emissions of the national electricity grid and associated infrastructure. The assessment focuses on the following key aims:

- Quantify the GHG emissions impact of the NEP to verify alignment with Eswatini's climate commitments under its NDCs

and obligations to UNFCCC. The goal is to ensure that by 2030, GHG emission reductions reach 14 per cent compared to baseline scenarios, requiring adequate assistance from external partners. Among the 13 mitigation strategies outlined in the NDC, 10 are specifically related to energy. The successful execution of the updated NDC depends on the effective implementation of NEP policy measures.

- Optimize the beneficial outcomes of the NEP concerning RE integration into the grid. The policy aims to provide the nation with economical and sustainable energy sources (aligning with SDG 7) while safeguarding the environment.
- Evaluate policy performance by examining the success of the NEP goals to increase RE-based electricity production, eliminate energy poverty and ensure universal energy access. While Eswatini's electrification has grown from 20 per cent in 2000 to 82.3 per cent in 2023, the challenge of providing electricity to all citizens has intensified due to rising demand. As the Government of Eswatini considers the dependency on imported energy as a risk factor, the success of the NEP requires finding the right balance between expanding access and developing sustainable electricity production capacity.

Policy description

This section provides basic information about Eswatini's NEP, which is important for reporting under the ETF of the Paris Agreement (see table CS.1).

Table CS.1. The Eswatini NEP

Name of policy	Policy position 3: To support the development of RE resources for a target of 50 per cent of the energy mix in electricity generation ²³
Description	The Eswatini NEP aims to achieve 50 per cent RE in the electricity generation mix. It is implemented through competitive auctions and tenders managed by the Eswatini Energy Regulatory Authority, enabling PPAs between IPPs and the Eswatini Electricity Company. The Short-Term Generation Expansion Plan includes 108.5 MW of committed renewable capacity (solar, hydro and biomass) and proposes 648 MW of additional capacity over the next decade. The policy is supported by the Energy Regulatory Act of 2007; the 2021 revised NDC, targeting a 14 per cent GHG reduction by 2030 (conditional on international support); and other energy sector frameworks. It seeks to promote low-carbon development, expand access to clean energy and reduce electricity import dependence, although a monitoring and evaluation framework has yet to be established. The proposed auctions up to 2030 are specified in the Short-Term Generation Expansion Plan as follows: ▪ 75 MW solar PV without storage in 2026 ▪ 50 MW solar PV with 100 MWh of storage in 2028 ▪ 50 MW solar PV with 100 MWh of battery storage in 2029 ▪ 100 MW wind power in 2028 ▪ 100 MW wind power in 2030 ▪ 10 MW hydropower expansion at Maguga dam in 2026 ▪ 80–135 MW hydropower at Ngwempisi dam in 2030 ▪ 60 MW biomass (woodchips and bagasse) in 2029 (request for proposal revised to 80 MW) ▪ 20 MW geothermal power plant in 2030
Policy objectives	The key objectives are to: - Ensure low-carbon economic development benefits from climate change mitigation resulting in a more sustainable future - Increase access to clean modern energy technologies

23. The Ministry of Natural Resources and Energy set an RE target of 50 per cent in the national electricity mix through the NEP, and the timelines for auctions are reflected in the national Energy Masterplan 2050 and its associated Short-Term Generation Expansion Plan.

Relevant NDC targets aligned with the policy (if applicable)	Not available
Implementing entity	Ministry of Natural Resources and Energy
Type of instrument	Auction and tendering
Status and start year of implementation	2026
Target year (time frame)	Up to 2030
Sector(s) affected	Energy

Policy key performance indicators

The following KPIs are also essential for reporting under the ETF of the Paris Agreement:

- The GHG emissions of Eswatini (see table CS.2)
- Existing RE power plants and projected additional generation from RE sources by 2030
- Number of jobs created in the RE sector
- The percentage change in Government revenues from the energy sector

- Number of household PV systems installed annually
- Number of systems in operation at end of the year
- Number of productive use applications commercialized per year

Table CS.2 presents the forecast of the capacity of RE technologies that will be added to the Eswatini national grid by the year 2030. The ICAT Methodology forecast is obtained by deducting other barrier impact from the financial barrier adjusted capacity. The average expert opinion forecast corresponds to the collective wisdom of leading national energy experts.

Table CS.2. GHG mitigation effects of the policy

Gases affected	CO ₂ , CH ₄ , N ₂ O
Estimates of GHG emission reductions in 2030 (ktCO₂e)²⁴	- ICAT Methodology forecast (RE1 scenario): 658 - Average expert opinion forecast (RE2 scenario): 572

24. That is, kilotonnes of carbon dioxide equivalent.

Methodological considerations and assumptions

This section presents details related to the GHG impact assessment, including the

methodology, scenarios, data requirements and other relevant aspects. Some of the information provided in table CS.3 is important for reporting under the ETF of the Paris Agreement.

Table CS.3. Overview of methodological considerations and assumptions

Methodology considerations	▪ Analysis approach: Ex-ante ▪ Emission calculations: Emissions trajectory method using the modelling of the Low Emissions Analysis Platform ▪ Technology: RE technologies
Time frame	2027–2030
Baseline scenario	In the business-as-usual (BAU) scenario, the GHG emissions of Eswatini are expected to increase to 1,339.30 ktCO ₂ e by the year 2029, with the addition of a 200 MW power plant. ²⁵
Project scenario	The project scenario involves implementing an RE policy that targets increased RE sources in Eswatini's local electricity generation mix as an alternative to the BAU coal-based pathway. Under this scenario, new generation capacity will be procured through competitive auction and tendering processes as prescribed by the Electricity Act of 2007.
Assumption	Baseline scenario: Project scenario: ▪ The assumption made in the study is that if more RE technologies are not installed, then fossil fuel (coal) plants will be added.
Data requirements	Baseline scenario: ▪ Total electricity demand for the year ▪ Total population for the year ▪ Annual growth rate of electricity demand per capita for the year ▪ T&D loss (%) and own use (%) ▪ Current electricity generation mix for each source (%) ▪ Emission factors per technology Project scenario: ▪ Annual capacity factor ▪ Annual average operation ▪ Technical capacity (see tables below) ▪ Emission factors per technology ▪ Revised electricity generation mix for each source (%)

25. Government of Eswatini.

Data requirements		<table><tr><th>RE source</th><th>Power capacity (MW)</th></tr><tr><td>Hydro</td><td>181.5</td></tr><tr><td>Solar PV</td><td>175</td></tr><tr><td>Wind</td><td>200</td></tr><tr><td>Biomass (woodchips and bagasse)</td><td>120</td></tr><tr><td>Geothermal</td><td>20</td></tr><tr><td>Total</td><td>696.5</td></tr></table>	RE source	Power capacity (MW)	Hydro	181.5	Solar PV	175	Wind	200	Biomass (woodchips and bagasse)	120	Geothermal	20	Total	696.5
	RE source	Power capacity (MW)														
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		<table><tr><th>RE source</th><th>ICAT methodology forecast (MW) (RE1 scenario)</th></tr><tr><td>Hydro</td><td>65.52</td></tr><tr><td>Solar PV</td><td>80.42</td></tr><tr><td>Wind</td><td>36.72</td></tr><tr><td>Biomass (woodchips and bagasse)</td><td>34.17</td></tr><tr><td>Geothermal</td><td>3.75</td></tr><tr><td>Total</td><td>220.58</td></tr></table>	RE source	ICAT methodology forecast (MW) (RE1 scenario)	Hydro	65.52	Solar PV	80.42	Wind	36.72	Biomass (woodchips and bagasse)	34.17	Geothermal	3.75	Total	220.58
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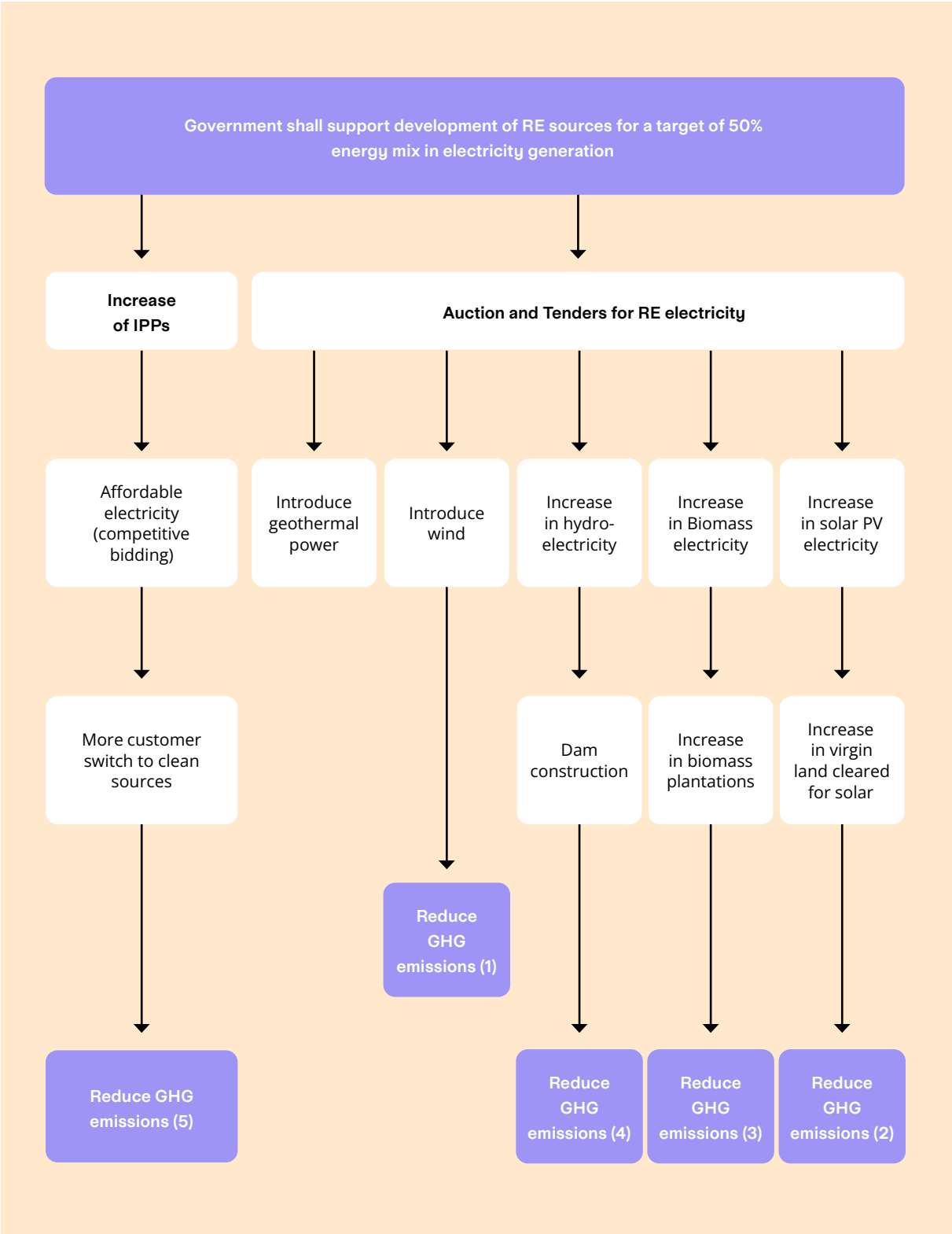
Policy causal chain

This section outlines the GHG impacts of the policy along with its intermediate effects, as applicable to the case study. Figure CS.2 presents a causal chain that illustrates how the policy (shown in dark blue) leads to GHG impacts (shown in light blue) through a series of interconnected cause-and-effect relationships (shown in white

boxes), progressing sequentially from policy implementation to the outcomes.

A key assumption underlying this analysis is that without the installation of additional RE infrastructure, fossil fuel-based coal plants would be developed to meet energy demand. The causal chain analysis demonstrates that the RE policy actions will result in a net reduction of GHG emissions.

Figure CS.2. Causal chain diagram in the context of Eswatini RE policy application and grid electricity generation



The causal chain framework is developed following the ICAT Renewable Energy Methodology and serves to assess both the likelihood and relative magnitude of potential GHG impacts (see table CS.4 for a

summary). Based on this assessment, impacts rated as minor in magnitude or having low likelihood of occurrence are excluded from the quantitative analysis.

Table CS.4. GHG impacts and source categories included/excluded in the GHG assessment boundary

GHG impact and GHG type	Likelihood	Relative magnitude	Included/excluded	Explanation
Reduction of GHG emissions (CO ₂ e) due to accelerated procurement of RE electricity options (solar, hydro, wind and geothermal energy)	Very likely	Major	Included	Eswatini's NDC baseline emissions for locally generated electricity includes a 200 MW coal-fired plant that is planned by the Government as a way of improving energy security and providing the baseload power. The RE policy position sets a 50% of RE target in the energy sources for the national grid to reduce GHG emissions in the electricity sector.
For biomass power plants, increase in emissions associated with stored bioenergy feedstock, agriculture and land-use change (CO ₂ , CH ₄ , N ₂ O)	Very likely	Minor	Excluded	Biomass feedstock used in electricity generation are byproducts of already existing industries – i.e., bagasse from sugar industries and woodchips from the timber industry.
Increase in GHG emissions (CO ₂) from decreasing carbon stock when solar plants are installed in virgin land	Very likely	Minor	Excluded	The land to be cleared is insignificant, with land-use change for solar plants from 0 to 50 kg CO ₂ e/MW6. Thus, emissions for 150 MW planned solar PV procurements are negligible.
Increase in GHG emissions (CO ₂ and CH ₄) from dam construction for hydropower	Possible	Moderate	Included	This is significant for RE policies involving hydropower plants with reservoirs.
Reduction in emissions (CO ₂ , CH ₄ , N ₂ O) from lower energy consumption due to increased cost	Possible	Minor	Excluded	This is considered insignificant for most RE policies.

The quantitative assessment includes two primary GHG impacts:

- Reduced GHG emissions:** Decreased CO₂ emissions resulting from accelerated deployment of RE sources (biomass, solar, hydro, wind and geothermal) into the national electricity grid to achieve the 50 per cent RE target in the generation mix
- Increased GHG emissions:** Elevated CO₂ and CH₄ emissions associated with RE infrastructure construction activities, particularly dam construction for hydropower projects

Baseline scenario and policy scenario

This section presents the case study results along with illustrative figures to support the findings.

Baseline scenario (business-as-usual)

The BAU scenario represents Eswatini's projected emissions pathway without additional RE interventions beyond existing capacity. Under BAU, GHG emissions are projected to reach 1,350 ktCO₂e by 2030, primarily driven by fossil fuel-based generation to meet growing electricity demand.

Table CS.5. Existing and projected RE generation capacity by 2030

RE source	Installed generation (MW)	Planned addition from RE sources (MW)	ICAT Methodology forecast (MW) (RE1 scenario)	Energy expert forecast (MW) (RE2 scenario)
Hydro	61.4	145	65.52	68.5
Solar PV	10.85	100	80.42	75
Wind	0	200	36.72	0
Biomass (residues)	106	60	34.17	60
Geothermal	0	20	3.75	0

Table CS.6. Emissions and mitigation outcomes by 2030

Scenario	Emissions in 2030 (ktCO ₂ e)	Avoided emissions in 2030 (ktCO ₂ e)	Avoided emissions in 2030 (%)
BAU	1,350	–	–
RE1	692	658	49%
RE2	778	572	42%

Policy scenarios

Two policy scenarios are used to assess the impact of RE deployment based on different forecasting approaches:

- a. **RE1 scenario – ICAT Methodology forecast:** This scenario applies the ICAT Renewable Energy Methodology to project RE capacity additions based on technical and economic feasibility assessments.
- b. **RE2 scenario – average expert opinion forecast:** This scenario incorporates collective expert judgement from leading national energy professionals regarding realistic RE deployment potential by 2030.

Both policy scenarios demonstrate significant emission reductions compared to the BAU baseline, with RE1 achieving 49 per cent emission reduction by 2030, and RE2 achieving 42 per cent.

Figure CS.3 shows the energy generation by technology under the BAU and RE1 scenarios.

Expanded assessment considerations

Stakeholders impacted

The project actively engaged key stakeholders to ensure ownership, relevance and effective utilization of the assessment report. Key engagements included the following:

- a. **Eswatini Meteorological Service** (climate change unit, Ministry of Tourism and Environmental Affairs): As the National Designated Authority for climate action, the Department was engaged early in the project to discuss the study and expected outcomes.
- b. **Department of Energy** (Ministry of Natural Resources and Energy): The Department, responsible for implementing the NEP, was engaged through briefings and a concept note shared with its Director. The Department of Energy formally endorsed the study, reflecting its critical role in overseeing energy policy direction and ensuring alignment with national energy objectives.

c. Implementing entities:

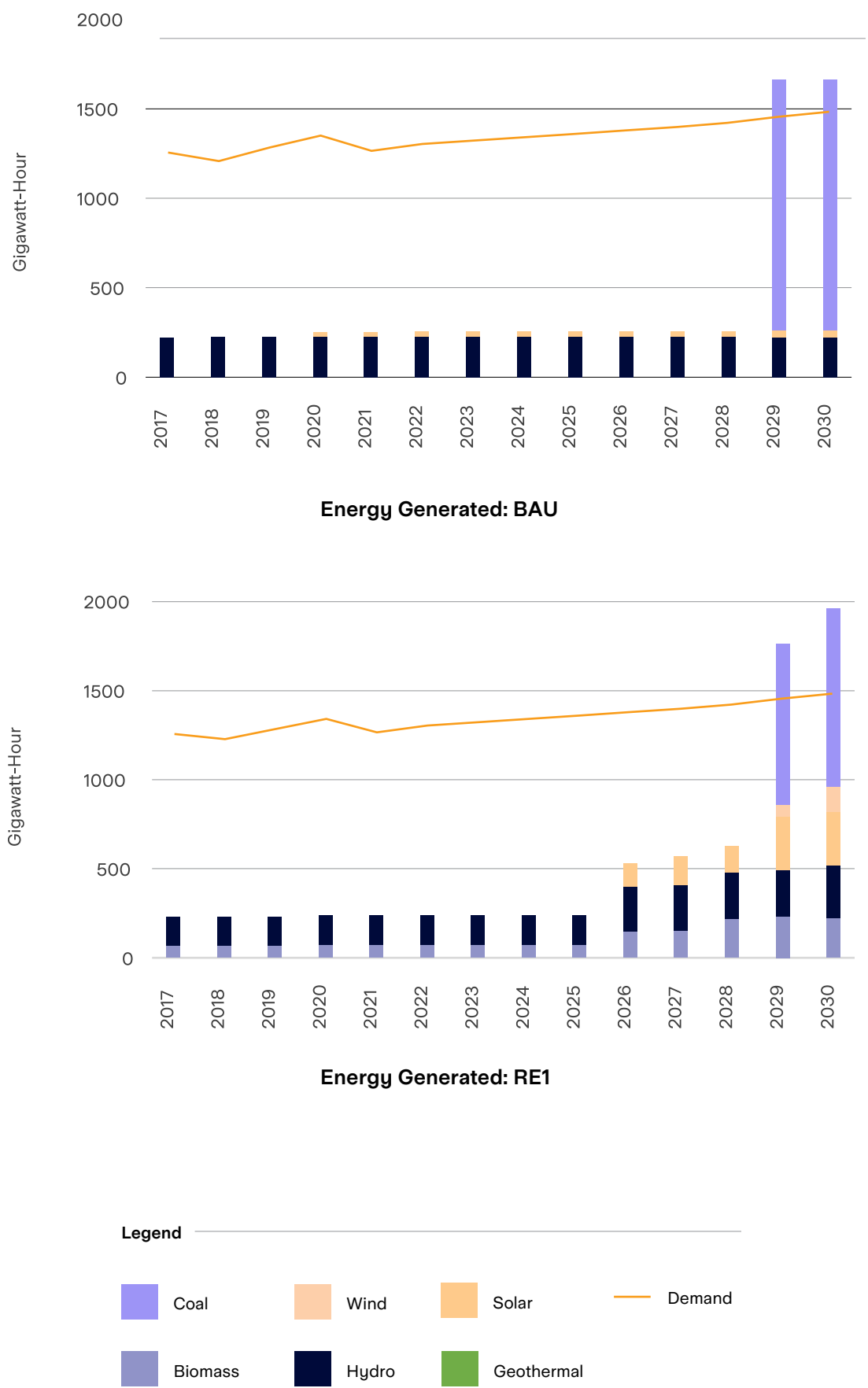
- **Eswatini Energy Regulatory Authority:** Responsible for the verification of periodic plans of energy consumption, production and T&D to ensure their adequacy and timely allocation
 - **Eswatini Public Procurement Regulatory Agency:** Administers public tenders and auctions, provides secretariat services to the Independent Tender Review Board, and monitors compliance with procurement regulations
 - **Eswatini Electricity Company:** Purchases, wheels and distributes electricity from IPPs to the national grid
- d. Monitoring and evaluation: Although a formal monitoring and evaluation plan was anticipated to be developed by 2019 and operational by 2023, it is yet to be established. Once operational, the monitoring and evaluation team from the Ministry of Natural Resources and Energy will play a key role in tracking policy implementation and ensuring data-driven adjustments to the NEP.

Lessons learned

The following key lessons were learned:

- a. RE expansion potential: The assessment demonstrated that Eswatini has significant potential to expand RE generation, with approximately 220.58 MW of additional capacity expected by 2030, alongside the existing 85.85 MW. This expansion could enable the country to meet its target of achieving at least 50 per cent of grid electricity from RE sources and significantly reducing dependence on electricity imports.
- b. Balancing energy security and climate goals: While planned coal power plants can improve energy security by providing baseload electricity, they also increase GHG emissions. The study showed that combining smaller coal power plants (<150 MW) with RE deployment could reduce

Figure CS.3. Energy generation by technology in the BAU scenario (left) and the RE1 scenario (right)



emissions by 42–49 per cent, highlighting the importance of balancing energy security with climate mitigation objectives.

- c. Importance of local expertise: Engaging national energy experts was critical for incorporating realistic assumptions regarding financial, technical and institutional barriers. This improved the accuracy of projections and ensured that the assessment reflected national circumstances rather than purely theoretical RE potential.
- d. Contribution to SDGs: RE expansion contributes to multiple SDGs, including SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth) and SDG 13 (climate action), showing that climate mitigation policies can have broader social and economic benefits.

India: Application of ICAT renewable energy methodology to assess GHG impacts of PM-KUSUM policy



Photo by John Rae from @UNOPS

Country context

India is one of the world's fastest-growing major economies and the third-largest electricity producer globally. While India has made significant strides in expanding generation capacity and grid access, challenges remain in ensuring affordable, reliable and sustainable energy, particularly in the agricultural sector.

Agriculture plays a central socioeconomic role, employing nearly half of India's workforce and supporting rural livelihoods. Irrigation is critical for agricultural productivity, especially given India's monsoon-dependent rainfall patterns. As a result, millions of farmers rely on expensive and polluting diesel-powered pumps for agriculture activities. Additionally, extensive support through free or subsidized electricity for irrigation for the sector has been provided by the Government, creating long-term fiscal stress and contributing to emissions from coal-based power generation. The subsidies are billed by distribution utilities, and they increased from US\$17 billion

(Rs1.44 trillion) in 2021/22 to US\$20 billion (Rs1.7 trillion) in 2022/23 (Power Finance Corporation, 2024).

To overcome such barriers, the Government has pursued ambitious clean energy targets, including 175 GW of renewable capacity by 2022 and 500 GW of non-fossil fuel capacity by 2030. Solar energy, in particular, has seen dramatic cost reductions through policy support from institutions such as the Solar Energy Corporation of India.

Despite this rapid utility-scale solar expansion, distributed RE in rural areas remained underdeveloped. Agricultural feeders and decentralized solar solutions presented an opportunity to simultaneously address multiple policy objectives: reducing subsidy burdens, improving power reliability for farmers, lowering diesel consumption and contributing to national climate commitments.

Within this broader energy-agriculture nexus, the Government launched the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) in 2019.

The scheme was designed to promote decentralized solar generation in the agricultural sector, enhance farmer incomes and support India’s clean energy transition while addressing structural inefficiencies in rural power supply.

Policy assessment objectives

The main policy assessment objectives include:

- Assessment of the expected and achieved change in terms of GHG emissions or removals, sustainable development impacts and extent of transformational change resulting from a policy or action
- Assessment of the role that the ICAT guide can play in the development of policies, enhancing the NDC update and implementation process, other climate

action, other relevant aspects of the Paris Agreement, and the use of the assessment results to raise resources

These assessments are expected to contribute to broader climate policy design and implementation, including the following:

- Improved quality of reporting to the UNFCCC (biennial transparency reports) and national communications
- New or refined policies and measures in support of a collective ambition in NDCs
- Improved climate and/or sustainable development policies

Policy description

This section provides basic information about India’s PM-KUSUM policy.

Table CS.7. Overview of PM-KUSUM policy

Name of policy	PM-KUSUM
Description	PM-KUSUM is a vital scheme aimed at enhancing synergies between the energy and agriculture sectors. From the implementation perspective, while the scheme is a national initiative, its actual implementation relies on state-level participation. This includes additional financial support provided by state governments beyond what is mandated by the scheme; determining tariffs for surplus solar power; determining installation timelines and penalties; and selecting vendors responsible for the design, supply, installation and commissioning of solar agriculture pumps. PM-KUSUM has three components: Component A: Setting up 10,000 MW of decentralized ground/stilt mounted grid-connected solar or other RE-based power plants by the farmers on their land Component A focuses on the development of RE-based power plants, with capacities between 500 kW and 2 MW, to sell the generated electricity to distribution companies (DISCOMs) at an FiT determined by the respective State Electricity Regulatory Commission. Participating DISCOMs would be eligible to receive a performance-based incentive of Rs0.40 (US\$0.0048) per unit purchased or Rs660,000 (US\$7,950) per MW of capacity installed (whichever is less) for a period of fiveyears from the commercial operation date. The Ministry of New and Renewable Energy (MNRE), in 2024, expanded the scope of component A to include other RE-based power plants. Component B: Installation of 1.4 million stand-alone solar agriculture pumps.

	Component B supports individual farmers in installing stand-alone solar-powered agricultural pumps with a capacity of up to 7.5 HP (horsepower) in off-grid areas. The MNRE, in 2024, revised the target for component B from the initial 1.75 million to 1.4 million stand-alone solar agriculture pumps. Under component B, 30 per cent of the cost is provided as central financial assistance (CFA). Additionally, at least 30 per cent subsidy is provided through the state government. Farmers have to bear 40 per cent of the costs of their solar water systems. The CFA contribution is 50 per cent in the case of special states (North-Eastern states, Sikkim, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Lakshadweep, and Andaman and Nicobar Islands). In these states, the state government will provide at least a 30 per cent subsidy, and the remaining 20 per cent of the cost is to be mobilized by the farmer. Component C: Solarization of 3.5 million grid-connected agriculture pumps, including feeder-level solarization (FLS) Under component C, individual farmers are supported to solarize their grid-connected agriculture pumps. It aims to reduce the burden of power subsidies on states by solarizing existing agricultural feeders and connections. A one-time capital investment could help reduce the recurring power subsidy burden. Power procured from decentralized solar units and plants located near the point of consumption could reduce the cost of power supply for the DISCOMs. Component C consists of two models: 1. Solarization of individual existing grid-connected pumps: Under this model, farmers with existing grid-connected pump sets are eligible for subsidies to solarize their connections. In addition to the benefit of adequate daytime supply, farmers would be able to sell any excess power to the grid at a predetermined tariff, gaining supplementary income. 2. FLS: Under this model, the DISCOMs could develop decentralized solar power plants near agricultural feeders to cater to the entire feeder loads, to reduce their cost of power supply to agricultural consumers. This model has similarities with component A and draws inspiration from the ongoing Mukhyamantri Saur Krushi Vahini Yojana scheme in Maharashtra.²⁶ This case study primarily focuses on components A and C, as these components are most relevant to the analysis. Both involve electricity generation that is supplied to the grid, thereby aligning closely with the ICAT methodology for assessing grid-connected RE impacts.
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26. In Maharashtra, Mission 2025 was set, with the objective was set to achieve 30 per cent feeder solarization by 2025 through the implementation of 7,000 MW of decentralized solar projects.

Policy objectives	The key objectives are to: - Provide energy and water security to farmers and enhance their income - De-dieselize the farm sector - Reduce environmental pollution by promoting solar power for irrigation and enabling farmers to sell surplus energy
Relevant NDC targets aligned with the policy (if applicable)	The policy reaffirms India's commitment to increase the share of installed capacity of electric power from non-fossil fuel sources to 50 per cent by 2030 and to reduce emissions intensity of its GDP by 45 per cent by 2030 from the 2005 level, as part of NDC targets.
Implementing entity	MNRE with the support of state implementing agencies
Type of instrument	A combination of FiTs and subsidies
Status and start year of implementation	March 2019 (completed)
Target year (time frame)	Seven years (policy closed on 31 March 2026)
Sector(s) affected	Energy and agriculture

Source: India, Ministry of New and Renewable Energy (MNRE) (2019); India, MNRE (2024).

GHG mitigation effects of policy

Table CS.8 below provides an overview of the estimated GHG reductions in both ex-ante scenario and ex-post scenario for components A and C.

Table CS.8. Overview of PM-KUSUM policy

Gases affected	CO₂
Estimates of GHG emission reductions (MTCO₂e per year)	Ex-ante estimation: - Component A: 13.17 - Component C: 0.115 Ex-post reported (GEF method): - Component A: 1.42 - Component C: 0.03

Methodological considerations and assumptions

Table CS.9 below provides an overview of the methodological considerations and assumptions for conducting the assessments.

Table CS.9. Overview of methodological considerations and assumptions

Methodology considerations	- Approach: Both ex-ante and ex-post - Technology: Solar
Baseline scenario	Scenario 1: Baseline scenario This scenario estimates emissions in the absence of the PM-KUSUM policy. It is based on the fossil fuel consumption patterns in 2019, the year preceding the scheme's launch. This provides a reference point for measuring the scheme's impact. For component A, the solar power plant is installed without any replacement of existing thermal power plants (so baseline emissions would be 0). Hence, mitigation potential from ex-post will be considered as the impact of the scheme. For component C, stand-alone solar agriculture pumps are planned to replace existing grid-connected electrical agriculture pumps and irrigation systems.
Policy scenario	Scenario 2: Ex-ante scenario In the ex-ante scenario, the GHG impacts are estimated based on the targets outlined for the implementation of PM-KUSUM. As the scheme is still ongoing, projecting its expected impacts is essential for understanding its potential contribution to emission reductions. Scenario 3: Ex-post scenario The ex-post scenario evaluates the scheme's actual impacts using data from its implementation between 2019 and 2025. As the programme is partially implemented, this scenario will help identify realized outcomes and inform recommendations for enhancing the scheme's effectiveness.
Assumptions	Policy scenario: For component C, it is assumed that 3.5 HP electric pumps are connected to the grid.

Data requirements	Baseline scenario: ▪ Consumption of diesel and electricity for agricultural pumps Policy scenario for component A: ▪ Installed capacity (MW) ▪ Capacity utilization factor ▪ GEF ▪ Electricity generated (MWh/year) Policy scenario for component C: ▪ Feeder-level electricity demand ▪ Solar generation data (plant load factor) ▪ Self-use versus grid export estimates ▪ GEF
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Policy causal chain

A causal chain describes the process by which a policy intervention leads to specific outputs, outcomes and impacts. It identifies intermediate effects and GHG impacts due to a policy change. The causal chain diagram for the assessment is provided in figure CS.4.

Component A leads to an increase in solar generation capacity, causing reduced emissions due to a shift in dependence from thermal power plants to solar power plants. At the same time, it is possible that the manufacturing of RE power plant equipment contributes to GHG emissions if the process, including transportation, is dependent on fossil fuel-based energy sources. However, life

cycle assessment of emissions indicates that the contribution of solar panels is significantly lower than the fossil fuel-based power systems (Peng, Lu and Yang, 2013). Component C (integrated power supply [IPS] as well as FLS) also leads to emissions reduction through the same causal explanation.

Component B leads to the replacement of diesel-based irrigation pumps with stand-alone solar pumps, thereby dropping GHG emissions by reducing diesel use and increasing the use of stand-alone solar pumps. The life-cycle assessment of GHG emissions from the manufacturing of solar power plant equipment are comparatively lower than those of a diesel-based power system (Mansour et al., 2024).

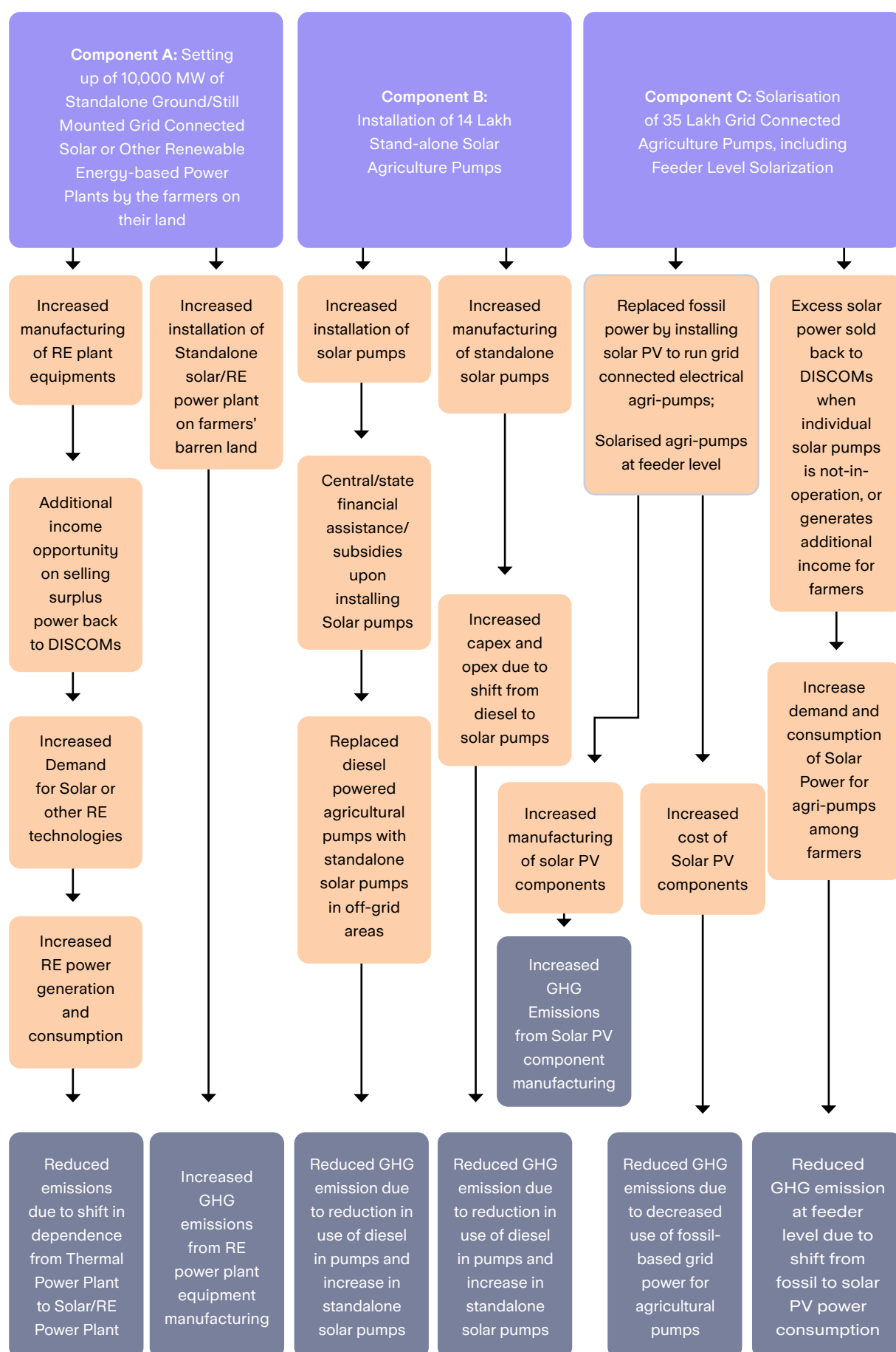
Figure CS.4. Causal chain diagram in the context of India RE policy application

Table CS.10. GHG sources and their impact under the PM-KUSUM scheme in the assessment boundary

GHG impact	Relevant GHGs	Likelihood	Relative magnitude	Included/excluded	Explanation
Reduced emissions due to shift in dependence from thermal power plant to solar/RE power plant	CO ₂	Very likely	Major	Included	Significant impact under the scheme
Increased GHG emissions from RE power plant equipment manufacturing	CO ₂	Possible	Minor	Excluded	Considered insignificant and is offset by decreased emissions from construction of fossil fuel power plants
Reduced GHG emission due to reduction in use of diesel in pumps and increase in stand-alone solarized pumps	CO ₂	Very likely	Major	Included	Significant impact under the scheme
Increased GHG emissions from solar pump manufacturing	CO ₂	Possible	Minor	Excluded	Considered insignificant and is offset by decreased emissions from manufacturing, diesel pumps and diesel use
Reduced GHG emissions due to decreased use of fossil-based grid power for agricultural pumps	CO ₂	Very likely	Major	Included	Significant impact under the scheme

Baseline scenario and policy scenario

Component A

The sanctioned portfolio totalled 10,000 MW; however, only 839 MW has been installed to date. The calculation shows an actual GHG mitigation of 1.42 MtCO₂ per year (ex-post:

2025) against a target of 13.17 MtCO₂ per year at the end of the policy period (ex-ante: 2019–2026). To meet the policy target, the available time until September 2026 is very limited, and it is unlikely that the target installation will be achieved. This shows a gap of 11.75 MtCO₂e of unmitigated emissions. The target (mitigation of

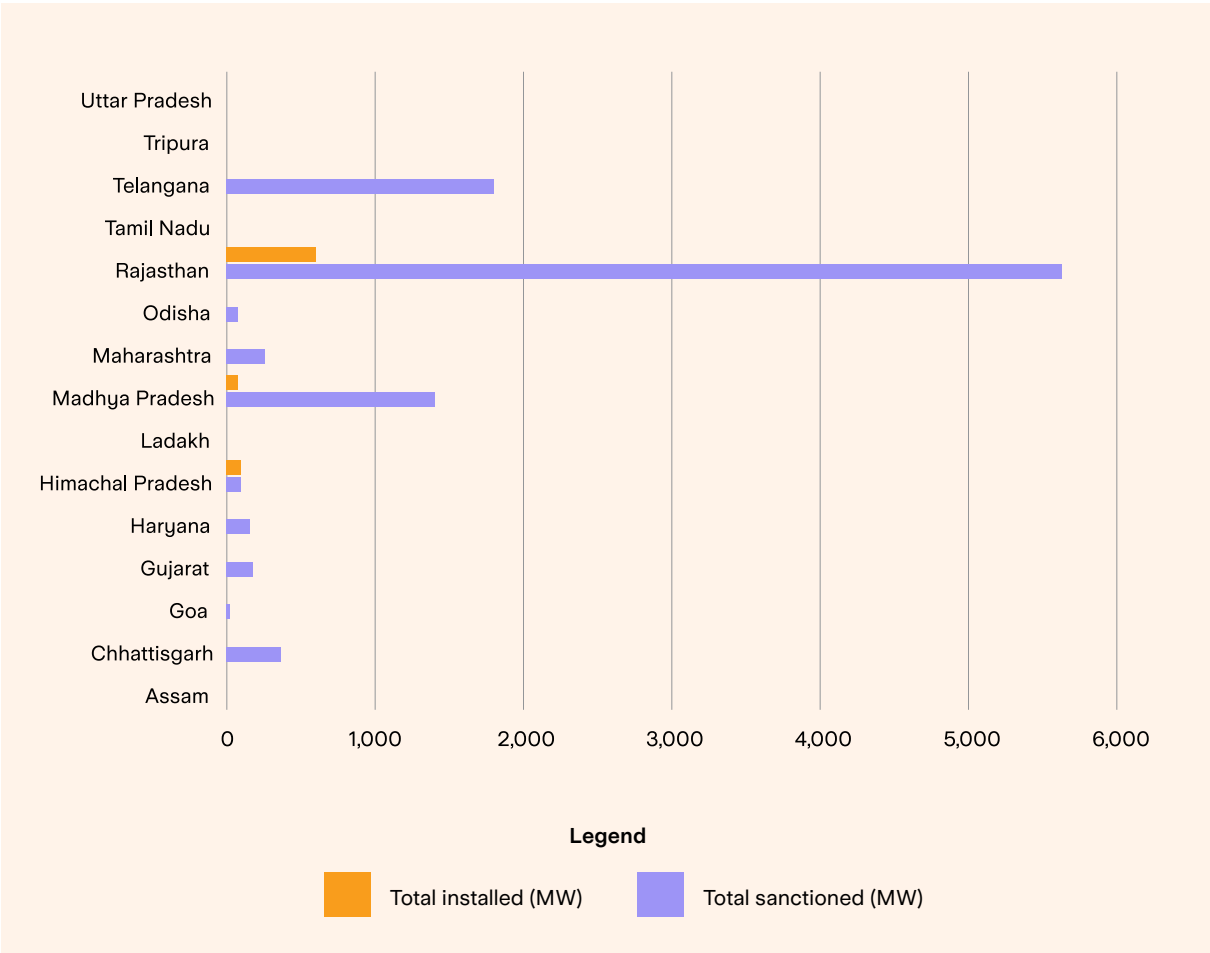
emissions) achieved is only 10.81 per cent (see table CS.11 for a summary of the results).

Figure CS.5 shows states by sanctioned capacity and installed capacity, where Rajasthan is driving the uptake of component A.

Table CS.11. Results for component A

Metric	Value
Total sanctioned capacity	10,000 MW
Total installed capacity	839 MW
Target GHG mitigation	13.17 MtCO ₂
Actual GHG mitigation	1.42 MtCO ₂
Target achieved	10.81%

Figure CS.5. States by total sanctioned and installed capacity (MW)



In table CS.12, Rajasthan also has the highest GHG mitigated, both targeted and actual. Clearly, commissioning and generation have not kept pace with plans and uptake of this

component. Contributing factors include delays in land permitting, limited progress on PPAs with DISCOMs, and slow developer mobilization.

Table CS.12. GHG mitigation in component A

State	Component A	
	Ex-ante GHG mitigation (MtCO ₂)	Ex-post GHG mitigated (MtCO ₂)
Chhattisgarh	0.4	0.01
Gujarat	0.1	0.00
Haryana	0.1	0.01
Himachal Pradesh	0.1	0.1
Madhya Pradesh	1.7	0.1
Maharashtra	0.2	0.00
Odisha	0.1	0.00
Rajasthan	8.3	1.2
Telangana	2.1	0.00
Total	13.17	1.42

Component C (IPS)

Uttar Pradesh, Kerala and Rajasthan together deliver 96 per cent of all realized mitigation. Other states show negligible ex-post impact. Where installations have happened in Uttar Pradesh, Kerala and Rajasthan, ex-post benefits have materialized at scale, validating the IPS design for mitigation. The calculation shows cumulative actual GHG mitigation of 0.03 MtCO₂ per year (ex-post: 2026) against

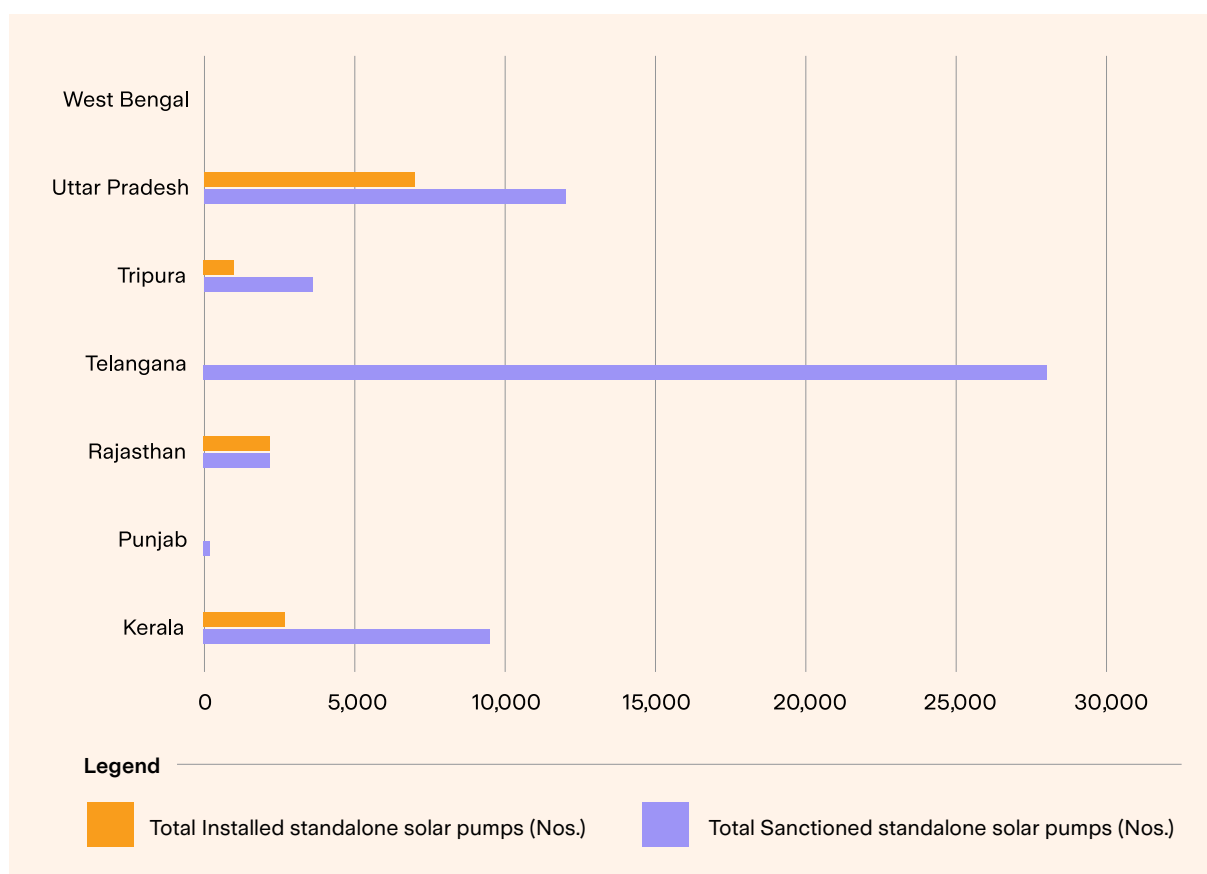
a target of 0.11 MtCO₂ per year (ex-ante: 2019–2026). This shows a gap of 0.08 MtCO₂ of unmitigated emissions. The target achieved is 23 per cent. See tables CS.13 and CS.15 for a summary of the results.

Table CS.13. Results for component C (IPS)

Metric	Value
Sanctioned solar pumps	55,392
Installed solar pumps	12,787
Electric pumps	20,781,689
Electricity consumption	44,888,448 ML
Target GHG mitigation	0.11 MtCO ₂
Actual GHG mitigation	0.03 MtCO ₂
Target achieved	23%

Figure CS.6 shows the states by sanctioned capacity and installed capacity, where

Telangana has the highest number of sanctioned solar pumps, with no installations.

Figure CS.6. States by sanctioned and installed solar pumps (nos.), as of 28 February 2026

In table CS.14, Uttar Pradesh has the highest GHG mitigated, both targeted and actual.

Table CS.14. GHG mitigation in component C (IPS)

State name	Ex-ante GHG mitigation (MtCO ₂)	Ex-post GHG mitigated (MtCO ₂)
Kerala	0.02	0.00568
Telangana	0.06	–
Tripura	0.01	0.002
Uttar Pradesh	0.02	0.01432
Rajasthan	0.004	0.000
Total	0.115	0.03

Telangana has 50 per cent of sanctioned solar pumps; however, Telangana has not delivered on installations. The low installation rate of 23 per cent of this component indicates that there are bottlenecks, and these include the

willingness to pay the upfront cost by farmers for solarization of electric pumps, as they are already receiving subsidized or free power from the state.

Component C (FLS)

Table CS.15. Results for component C (IPS)

Metric	Value
Sanctioned solar pumps	3,513,602
Installed solar pumps	1,341,892
Target GHG mitigation	5.58 MtCO ₂
Actual GHG mitigation	2.78 MtCO ₂
Target achieved	50%

Maharashtra, Gujarat and Rajasthan account for 89 per cent of realized mitigation. However, there have been challenges in the implementation processes in Uttar Pradesh, Andhra Pradesh and Bihar; these states have not been able to materialize the installations at the same rate as other states. The calculation shows cumulative actual GHG mitigation of 2.78 MtCO₂ per year (ex-post: 2025) against

a target of 5.58 MtCO₂ per year (ex-ante: 2019–2026). This shows a gap of 2.8 MtCO₂ of unmitigated emissions. The target achieved is only 50 per cent.

Figure CS.7 shows the states by sanctioned capacity, where Maharashtra has the highest number of sanctioned capacity.

Figure CS.7. States by sanctioned capacity and installed solarized pumps (nos.), as of 28 February 2026

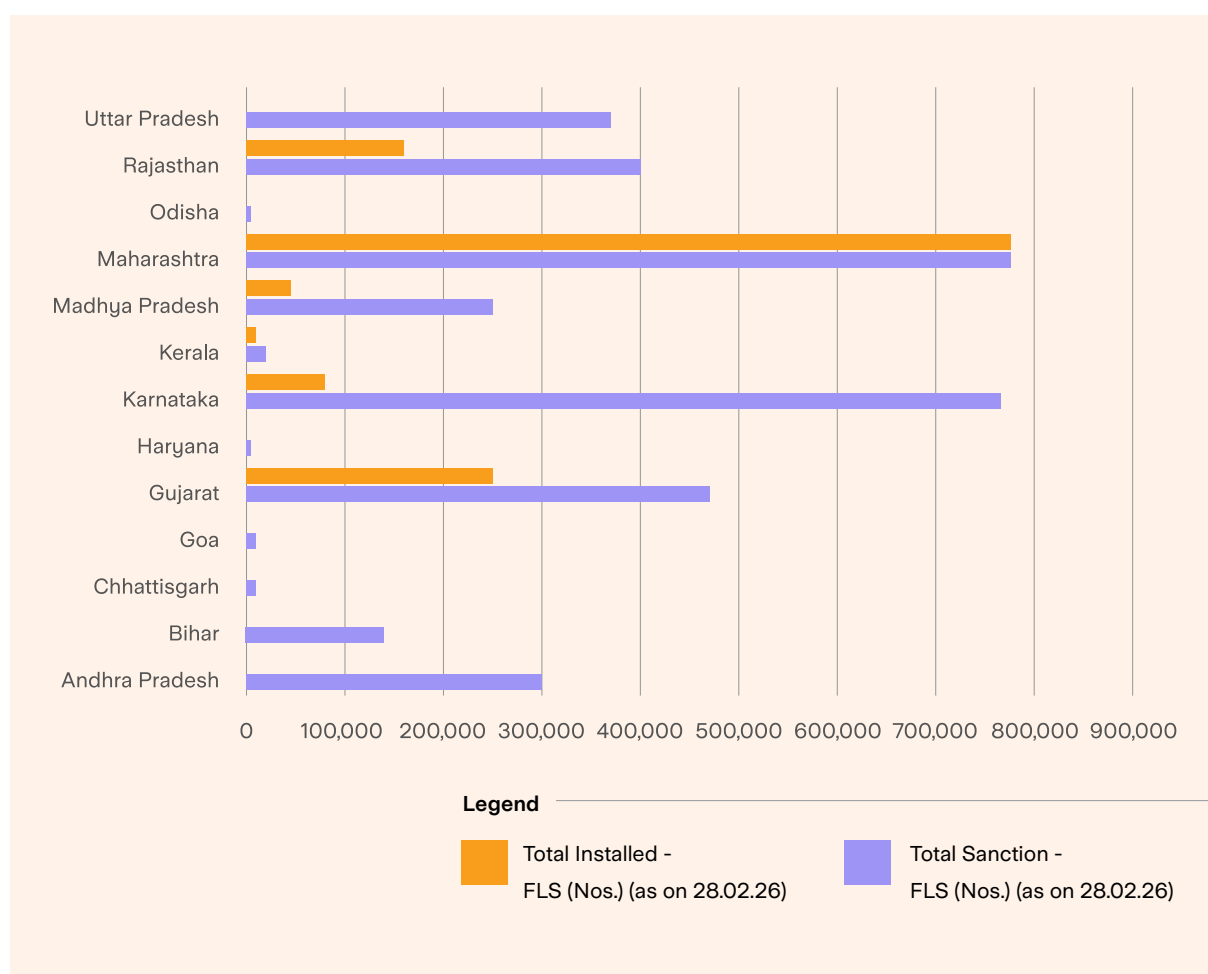


Table CS.16 shows the Maharashtra GHG mitigation, both targeted and actual.

Table CS.16. GHG mitigation in component C (FLS)

State name	Component C (FLS)	
	Ex-ante GHG mitigation (MtCO ₂)	Ex-post GHG mitigated (MtCO ₂)
Andhra Pradesh	0.47	–
Bihar	0.22	–
Chhattisgarh	0.02	–
Goa	0.02	0.00
Gujarat	0.74	0.53
Karnataka	1.21	0.04
Kerala	0.04	0.02
Madhya Pradesh	0.40	0.10
Maharashtra	1.23	1.61
Odisha	0.01	–
Rajasthan	0.64	0.34
Uttar Pradesh	0.59	–
Total	5.58	2.78

States like Uttar Pradesh, Andhra Pradesh and Bihar show little installed capacity, indicating challenges regarding lack of access to land near substations, infrastructure-related limitations (including the grid for evacuation of power not being ready and lagging local permissions), and uncertain payment security. For the viability of component C, FiT is a critical

determinant. The tariff should be sufficiently attractive for farmers to export surplus power in IPS and sell it in FLS. The tariff is determined by a competitive bidding process by the State Electricity Regulatory Commission for some states, as in Rajasthan, while other states rely on regulatory orders.

Lessons learned

The following key lessons were learned:

1. **Alignment with renewable purchase obligation (RPO) targets:** Since 2010–2011, the Ministry of Power has used RPO as an instrument to meet NDCs and promote RE deployment.²⁷ Decentralized agricultural solar can contribute towards state RPO through components A and C. These components are structured to feed power into the grid via state-determined tariffs and PPAs, aligning agricultural solarization with utility obligations.

Evidence from Jaipur DISCOM indicates initial misalignment with state RPO targets; however, successful PM-KUSUM uptake has since prompted the DISCOM to begin aligning sanctioned capacity. DISCOMs need time to align these components with their power purchase planning to maximize benefits from implementation. Early signs of transformation are observed when DISCOMs take ownership of this alignment. This momentum can be sustained if the central Government strengthens RPO regulations, enabling DISCOMs to plan for RPO fulfilment through components A and C power plants. The ICAT Renewable Energy Methodology references biofuels obligations and mandates similar to RPO obligations in its methodology overview but does not incorporate them into the methodology itself.

2. **Tariffs regulated by states:** The innovative process of inviting tariff-based bids for grid-connected solar power projects was adopted during the Jawaharlal Nehru National Solar Mission in 2010. The solar tariff approved by the Central Electricity Regulatory Commission was Rs17.91/kWh in 2010–2011; since then, tariffs have fallen considerably, reaching Rs2/kWh in 2022. Tariff discovery proceeds via competitive tenders and committee negotiations. Open

tenders allow broad participation from developers: the technical bid and then the financial bid are opened, and each can propose its own tariff rate. These rates are negotiated and finalized by the committee; the petition is then submitted to the regulator, which approves them.

The MNRE domestic content requirement for module production has increased CAPEX, as imported module prices are much lower.²⁸ In September 2024, MNRE decided to reimpose the domestic content requirement, effective 1 June 2024 (Grover, 2025). CFA under the PM-KUSUM scheme is conditional on using domestically manufactured solar components (solar cells and modules) – except where a waiver applies. However, given the CFA provided and the prevailing tariff rates, using domestically produced modules is not financially viable. The Rajasthan Electricity Regulatory Commission reported that bidders were asked to agree to counter-offer tariffs, indicating that changes in domestic content requirements affect tariffs. The ICAT Renewable Energy Methodology demonstrates that a country's regulatory agencies and public utilities are responsible for designing and implementing RE policies. FiT policies aim to promote RE deployment by offering long-term purchase agreements with power producers at a specified price per kWh. They provide predictable long-term revenue, crucial for securing project finance. Developers under PM-KUSUM sign 25-year PPAs with DISCOMs at a pre-fixed FiT. Low FiTs disincentivize participation in PM-KUSUM, as developers cannot cover operation, maintenance and land-leasing costs at these tariff levels.

3. **Land policy regulated by the states:** As land is a state subject, regulatory clarity on land leasing is uneven across states. Land-leasing rates differ, affecting the

27. The list of RPO regulations can be accessed at www.recregistryindia.nic.in/index.php/publics/Reference_Documents.

28. Imported modules for 1 MW plant cost Rs27.5 million; while under domestic content requirement, the same capacity costs Rs. 44 million.

compensation that farmers receive from developers.

Land aggregation is required to set up solar power plants in component A; the minimum requirement is one hectare, but landholdings tend to be less than this. The PM-KUSUM Dashboard, the national monitoring portal (see point 6 below) however, at times incorrectly reports that land aggregation is unavailable, creating a gap in information between the land that has been aggregated and what has been recorded in the portal.

In component C, there were difficulties in acquiring suitable land near substations, as some government land was unusable. Land acquisition delays can stall progress. If commercial activities like agrivoltaics are undertaken on agricultural land for more than two years,²⁹ the land is automatically reclassified as commercial; such land-use rules require reform. New policies should be designed to increase the feasibility of Farmer Producer Organizations to retain land and project ownership.

The ICAT Renewable Energy Methodology and Sustainable Development Methodology do not provide evidence on how land reforms can increase the deployment of RE. However, the ICAT Sustainable Development Methodology broadly discusses the identification and promotion of policies that contribute to multiple SDGs. Agrivoltaics is an SDG enabler, impacting the following SDGs:

- SDG 2 (zero hunger): Allows farmers to grow crops under solar panels while earning income from leasing their land and diversifying their livelihood
- SDG 7 (affordable and clean energy): Directly adds RE capacity without requiring additional land
- SDG 8 (decent work and economic growth): Provides farmers with additional

income from leasing land and selling power

- SDG 13 (climate action): Supports mitigation by expanding RE generation.

Early signs of transformation are observed when the state takes ownership in undertaking land reforms that will encourage the deployment of RE.

4. **Capacity of state implementing agencies:** The implementation of PM-KUSUM is uneven across states, reflecting differences in the technical and administrative capacity of state implementing agencies.

Punjab is one of the poorest-performing states in this regard. Under PM-KUSUM, pumps up to 15 HP capacity are permitted, but subsidies are only offered up to 7.5 HP. Pumps rated 7.5–15 HP therefore receive only the subsidy amount applicable to a 7.5 HP pump. As low water levels and large landholdings require higher capacity pumps, this cap limits uptake. Implementation in Punjab is also centralized: All PM-KUSUM components are handled by a single state nodal agency (SNA), the Punjab Energy Development Agency. Across all states, SNAs shoulder the complex tasks of tendering, vendor oversight, installation verification, timely operation and maintenance, and regular progress reporting to MNRE and the Central ministry. However, as energy agencies, SNAs typically have limited experience working directly with farmers.

Haryana is one of the top-performing states; implementation is shared between the SNA – Haryana Renewable Energy Development Agency – and state DISCOMs. Component B is handled by the SNA, and components A and C are handled by the DISCOM.

Rajasthan is the most successful state across all three components, with a decentralized implementation structure: component A is managed by the SNA, Rajasthan Renewable Energy Corporation

29. Agrivoltaics combines agriculture and solar power on the same land.

Limited; component B by the Horticulture Department; and component C by the state DISCOM. Component B's success owes much to the Horticulture Department's extensive network of block and field staff, who raise awareness and disseminate knowledge about agricultural subsidies.

There is also convergence across schemes – such as PM-KUSUM, the Pradhan Mantri Krishi Sinchayee Yojana, the Rashtriya Krishi Vikas Yojana Remunerative Approaches for Agriculture and Allied Sector Rejuvenation, and the Atal Bhujal Yojana – whose objectives often overlap, so state implementing agencies should coordinate and collaborate with them. The Atal Bhujal Yojana is a groundwater management scheme aimed at improving water-use efficiency and enhancing groundwater recharge. The outputs from this scheme can feed into PM-KUSUM and build the capacity of state implementing agencies.

The ICAT Renewable Energy Methodology identifies a lack of strong, dedicated institutions as a key barrier to policy implementation, creating institutional and administrative obstacles. The ICAT Sustainable Development Methodology highlights training and capacity-building of stakeholders – including government staff, utilities and regulatory commissions – as critical enabling actions. In states such as Rajasthan and Haryana, effective implementation has produced early signs of transformational local ownership.

5. **Coordination between MNRE, the SNA, DISCOMs, the Irrigation Department, the Department of Revenue and the Department of Agriculture:** Horizontal coordination among MNRE, SNAs and DISCOMs is critical for implementing all components. MNRE's key functions include policy formulation – including the issuance of operational guidelines, technical specifications and financing norms – and releasing CFA to SNAs for components B and C. Depending on the component, the

SNA or the DISCOM is responsible for land identification and approvals, procurement and tendering, grid connectivity, and payments to developers and farmers.

In the initial stage of PM-KUSUM implementation, effective coordination between the MNRE, SNAs and DISCOMs lays the foundation for operationalizing the scheme's objectives, focusing on policy alignment, resource allocation and target-setting mechanisms. The second stage focuses on ground-level operationalization, with DISCOMs and SNAs acting as central facilitators, coordinating with farmers and the Department of Revenue, Department of Agriculture and Irrigation Department.

Evidence obtained from Jaipur DISCOM indicates that coordination between MNRE, SNA and the DISCOM is functioning well, as MNRE regularly monitors the commissioned capacity. If a DISCOM is unable to sign enough PPAs and commission capacity, it is required to surrender that capacity to the SNA. However, while MNRE, SNAs and DISCOMs have established operational modalities, integration with indirect stakeholders – such as the Irrigation Department, Department of Revenue and Department of Agriculture – remains fragmented.

As the ICAT Renewable Energy Methodology notes, complex interactions and insufficient coordination between the various authorities involved call for institutional and administrative reforms. As the ICAT Sustainable Development Methodology observes, policies may not achieve their full potential due to governance challenges such as insufficient capacity, weak inter-agency coordination, limited public participation or lack of accountability.

6. **Monitoring and reporting system:** The PM-KUSUM Dashboard – the national monitoring portal hosted by MNRE – captures state-wise progress across all other portals, including solar installations,

pump development and feeder-level data. The portal reports sanctioned versus commissioned data but omits intermediate metrics: For sanctioned capacity, it does not capture tenders issued or letters of award; for commissioned capacity, it does not report on signed PPAs.

The United Kingdom of Great Britain and Northern Ireland-India Supporting Structural Reform in the Indian Power Sector programme assisted MNRE in designing the Solar Energy Data Management System, which is a platform enabling real-time data integration from state monitoring systems, as well as tracking solar pump and plant performance, which strengthens accountability in subsidy approvals. In accordance with prescribed format and guidelines, SNAs integrate quarterly reports – including maintenance and performance metrics – into the MNRE system. These reports are prepared by engineers who visit field sites to collect performance data.

In states such as Rajasthan, PPAs are cancelled if the project development timelines are not met. The ICAT Renewable Energy Methodology recommends using monitoring reports, surveys and installation registers to measure installed RE capacity.

7. **Training and outreach mechanisms among farmers:** Farmers are key beneficiaries for installing solar pumps, leasing land for decentralized lands and selling surplus power. However, awareness of the PM-KUSUM scheme is low among small farmers, while uptake is higher among those with larger landholdings. Greater collaboration is required among implementing agencies – including the irrigation, agriculture, and horticulture departments across all states – to create awareness and training.

The ICAT Renewable Energy Methodology notes insufficient knowledge among potential users about the availability, benefits and performance of RE, but calls for greater clarity on how to raise awareness among the different types of RE end users.

8. **Grid infrastructure readiness:** The readiness of grid infrastructure is central to the success of PM-KUSUM, particularly for components A and C. MNRE guidelines require DISCOMs to ensure that substations, feeders and evacuation infrastructure are prepared for project commissioning. However, readiness varies widely across states.

In Odisha, where the scheme has underperformed, feeder segregation is not in place, and weak substations have delayed solarization. As component A power plants connect directly to substations, poor substation maintenance by many DISCOMs frequently causes tripping of the entire substation. Component C (FLS) focuses on solarizing feeder lines by setting up decentralized solar plants near agricultural feeders; net metering allows farmers to sell surplus solar power to the electricity grid. The last-mile infrastructure is critical but often overlooked in scheme planning. DISCOMs assign the lowest priority to agricultural feeder networks because revenue recovery is too low, a concern also raised by developers.

Nonetheless, successful projects exist. In Karnataka, nine villages in Bengaluru have reduced the burden on the Bangalore Electricity Supply Company (BESCOM) grid by supplying 68 MW of electricity daily. BESCOM aims to save 2,400 MW daily once all 150 planned KUSUM-C stations are operational (Kaggere, 2025). Grid upgrading at the distribution level is critical and can be facilitated by convergence with other schemes, such as the Revamped Distribution Sector Scheme.

The ICAT Renewable Energy Methodology highlights a lack of flexibility in the energy system, specifically electricity grids, to integrate or absorb RE. Energy markets are not prepared for RE – i.e., for the integration of intermittent energy sources and that grid connection and access are not fairly provided. Grid connection costs are higher for RE, and there is a history of technical

problems with grid infrastructure that prevent decentralized access to the grid for RE.

9. **Capital and operating expenditure affordability for farmers:** Capital investment and operational costs are too high for small farmers. The cost of a solar power plant is Rs35–40 million/MW. Component A carries no subsidy, while component C offers a 60 per cent subsidy from the state and central governments, resulting in an upfront cost of Rs14–26 million. For component B, a 3 HP solar pump costs Rs180,000–250,000, of which the farmer contributes Rs45,000; and a 5 HP pump costs Rs250,000–350,000, of which the farmer pays Rs65,000. These CAPEX levels are too high for small and marginal farmers, which effectively limits participation in the scheme to larger operators. Operating expenditure for a utility-scale plant is Rs200,000–250,000/MW, rising to Rs450,000–500,000/MW for small-scale distributed plants. As a result, the scheme does not ensure equity and inclusion for small and marginal farmers.³⁰

The ICAT Renewable Energy Methodology and Sustainable Development Methodology do not provide evidence on the impact of RE on end users, who are the farmers in this case.

10. **Community ownership models:** Achieving equity and inclusion requires a shift from individual to community-based participation models. Leveraging cooperatives, panchayats, Farmer Producer Organizations, and Water User Associations can enable collective decision-making, shared ownership, and pooled resources, especially for smallholders.

While component A provides for these collective ownership and partnership models, they have not been widely adopted in practice. Farmer Producer Organizations encourage community-based land aggregation, but fragmented landholdings make pooling difficult, and the Farmer

Producer Organizations lack the capacity-building support needed to participate effectively in the scheme.

The ICAT Renewable Energy Methodology emphasizes that building trust, collaboration, shared ownership and support for policies among stakeholder groups is critical for smoother policy implementation.

11. **Availability of concessional finance and credit:** Many banks classify component A projects as high risk, owing to payment delays from DISCOMs, the absence of central and state subsidies, and a lack of guarantees. With margin money requirements set at 30 per cent of total project cost (CUTS International, 2023), many farmers who successfully acquired bids were unable to implement them due to the large equity contribution required and difficulty securing loans. Farmers have demanded a loan-to-equity ratio of 9:1, which banks have been unwilling to accept.

According to MNRE guidelines, loans for feeder segregation can be taken from the National Bank for Agriculture and Rural Development, the Power Finance Corporation or the Renewable Energy Corporation. Similar guidelines for the provision of loans for solar power plants to farmers in component A could be introduced. The National Agriculture Infra Financing Facility could also be utilized to finance component A projects. Under the Mukhyamantri Laghu Udyan Protsahan Yojana, a 6 per cent interest subvention was provided, which encouraged farmers to set up solar power plants.

CFA should be increased in components B and C, particularly if domestically manufactured modules need to be promoted, given that imported modules remain significantly more cost-effective. To promote equity and inclusion through community-based approaches, a subsidized credit window via the National

30. Data drawn from stakeholder interviews.

Bank for Agriculture and Rural Development targeted at holdings of less than two hectares should be established.

The ICAT Renewable Energy Methodology and Sustainable Development Methodology offer no evidence on how the availability of concessional finance and credit can increase the adoption of RE.

12. **Payment reliability from DISCOMs:** With the exception of a few states – Karnataka, Rajasthan and Gujarat – DISCOMs have routinely failed on timely payments. States should implement financial security mechanisms, such as payment assurances, to ensure regular payments to developers and farmers. Rajasthan has led the way, enforcing payment assurances to protect developers and farmers, while boosting banks' confidence in financing farmers to set up solar plants.

The ICAT Renewable Energy Methodology and Sustainable Development Methodology offer no evidence on how implementing partners can be made more reliable in ways that encourage RE deployment.

13. **Water-use efficiency:** Groundwater plays a key role in boosting agricultural production, but the subsidized power has led to widespread overuse of irrigation pumps and overextraction of the resource.

In Punjab, a study by the Mahatma Gandhi State Institute of Public Administration linked groundwater depletion to agricultural electricity supply. Cost-reflective electricity pricing is the long-term solution to address concerns on groundwater overuse (Rahman et al., 2023). However, given political sensitivities, states that provide subsidized electricity supply should consider complementary strategies for groundwater management, as free or subsidized supply of electricity typically drives higher extraction.

The Paani Bachao, Paisa Kamao scheme was voluntary, and it employed a direct benefit transfer model to incentivize farmers

to use electricity and water judiciously. The impact of PM-KUSUM on water-use efficiency still needs more clarity, as experts have suggested that impacts on groundwater are detectable only in the long term. The effect of agrivoltaics (Agri-PV) on water-use efficiency is more robust: panel shade reduces heat and wind, cutting evapotranspiration and retaining soil moisture between irrigation cycles. Field data indicate that Agri-PV can reduce irrigation water use by up to 20 per cent (Jat, Poonia and Santra, 2025).

Water-use efficiency is addressed under SDG 6, which focuses on ensuring access to clean water and sanitation for all. The ICAT Sustainable Development Methodology cites an SDG monitoring plan for cities that sets a 2030 target to substantially increase water-use efficiency across all sectors, ensure sustainable freshwater withdrawals, and substantially reduce the number of people affected by water scarcity. The indicator used to measure change is water-use efficiency over time.



Photo by American Public Power Association

References

Abbreviations and acronyms

BAU	Business-as-usual
BM	Build margin
CAPEX	Capital expenditure
CFA	Central financial assistance
CH₄	Methane
CM	Combined margin
CO₂	Carbon dioxide
CTF	Common tabular format
DISCOM	Distributing company
EMS	Energy management system
ESaaS	Energy storage-as-a-service
ETF	Enhanced transparency framework
FiT	Feed-in tariff
FLS	Feeder-level solarization
GDP	Gross domestic product
GEF	Grid emission factor
GHG	Greenhouse gas
HP	Horsepower
ICAT	Initiative for Climate Action Transparency
IEA	International Energy Agency

IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
IPS	Integrated power supply
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
ITCs	Investment tax credits
KPI	Key performance indicators
LCOE	Levelized cost of electricity
LCOS	Levelized cost of storage
MNRE	Ministry of New and Renewable Energy (India)
MPG	Modalities, procedures and guidelines
MW	Megawatt
MWh	Megawatt hour
N₂O	Nitrous oxide
NDCs	Nationally determined contributions
NPV	Net present value
NREL	National Renewable Energy Laboratory (National Laboratory of the Rockies)
OECD	Organisation for Economic Co-operation and Development
OM	Operating margin
PACM	Paris Agreement Crediting Mechanism
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan Yojana

PPA	Power purchase agreement
PPP	Public-private partnership
PTC	Production tax credit
PV	Photovoltaic
RE	Renewable energy
RFP	Request for proposals
RPO	Renewable purchase obligation
RPS	Renewable portfolio standards
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goal
SNA	State nodal agency
T&D	Transmission and distribution
TOU	Time-of-use
UNFCCC	United Nations Framework Convention on Climate Change
UPME	Unidad de Planeación Minero-Energética (Colombia)
VAT	Value-added tax
VRE	Variable renewable energy
WACC	Weighted average cost of capital

Glossary

A

Assessment boundary

The critical initial step in any sustainability reporting or impact analysis where the organizational and operational limits of the evaluation are set. This delineation specifies which entities, activities, facilities and time periods are included or excluded from the performance measurement. Source: <https://esg.sustainability-directory.com/area/defining-assessment-boundaries/resource/1>

Auction (competitive bidding; also called tendering)

A procurement mechanism by which RE supply or capacity is competitively solicited from sellers, who offer bids at the lowest price they would be willing to accept. Bids may be evaluated on both price and non-price factors

Avoided emissions

The quantity of CO₂ emissions that have not been emitted to the atmosphere as a result of the implementation of human interventions with lower or no GHG emissions. Avoided emissions can be reported over a period of time, comparing emissions of a BAU scenario (without the implementation of an emission reduction strategy) with the actual emissions after the implementation of a reduction strategy. Source: https://ghgprotocol.org/sites/default/files/ghgp/Avoided%20emissions%20survey%20report_final%20draft.pdf

B

Baseline scenario

Establishes a projected state of conditions against which the effects of a specific policy, project or investment are measured. It represents the hypothetical future trajectory if current trends and policies continue without the proposed intervention being implemented. Source: <https://esg.sustainability-directory.com/area/baseline-scenario>

Battery storage/ grid-battery storage

A technology in the RE landscape enabling excess power generated from renewable sources, such as solar and wind, to be stored and used when production is lower than consumption. Source: <https://europeanenergy.com/green-solutions/battery-storage>

Biomass energy

Energy derived from combustion of solid, liquid and gaseous biomass fuels in high-efficiency conversion systems, which range from small domestic appliances to large-scale industrial conversion plants. Modern applications include heat and electricity generation, combined heat and power, and transport.

C

Capacity factor

The ratio of the actual output of a unit of electricity or heat generation over a period of time (typically one year) to the theoretical output that would be produced if the unit were operating without interruption at its rated capacity during the same period of time.

Carbon dioxide (CO₂)

A colourless, tasteless, odourless gas that is naturally present in the Earth's atmosphere and is produced by all living organisms. In humans, it is removed from the body in air breathed out. It can also be human-made. Source: www.gov.uk/government/publications/carbon-dioxide-properties-and-incident-management/carbon-dioxide-general-information

Causal chain

The sequence of events leading up to some final effect, where each member of the sequence causes its succeeding member to come about. Source: www.oxfordreference.com/display/10.1093/oi/authority.20110803095555907

Common tabular format (CTF)

Standardized tables adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for electronic reporting of quantitative information by Parties under the ETF.

Crediting period (for policies)

The period in which verified GHG emission reductions or removals attributable to a mitigation activity can result in the issuance of carbon credits. Source: <https://icvcm.org/wp-content/uploads/2024/02/CCP-Section-5-V2-FINAL-6Feb24.pdf>

Curtailment

The deliberate reduction of electricity output from an RE plant (e.g., wind or solar farm) below what it is capable of producing. This usually happens if the grid is congested or if there is more power being generated than the system can safely handle.

Curtailment factor

A mathematical percentage or ratio used to estimate how much potential RE will be lost due to grid limitations. For example, a curtailment factor of 0.10 (10 per cent) means that 10 per cent of the energy produced by the plant will not reach the grid and therefore will not contribute to reducing GHG emissions.

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A mathematical percentage or ratio used to estimate how much potential RE will be lost due to grid limitations. For example, a curtailment factor of 0.10 (10 per cent) means that 10 per cent of the energy produced by the plant will not reach the grid and therefore will not contribute to reducing GHG emissions.

D

Dispatchability

The ability of a resource to turn on or off, or to increase or decrease its power output, on demand during normal operating conditions. Source: <https://rmi.org/reality-check-dispatchability-and-reliability-are-not-the-same-thing>

Distributed generation

The generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption.

E

Electricity generation mix

The combination of the various fuels used to generate electricity in a given geographic region. Source: www.planete-energies.com/en/media/article/what-power-generation-mix

Emissions trajectory modelling/ method

A quantitative approach used to project the future course of GHG or pollutant releases over a specified time frame. The concept provides a framework for understanding how current policies and technological changes might alter future environmental impact. Source: <https://esg.sustainability-directory.com/area/emission-trajectory-modeling>

Energy management system (EMS)

Software that helps utilities to plan, optimize and operate the power grid in real time. It balances electricity supply and demand, integrates RE and ensures reliable power delivery. Together, the two systems monitor the grid and make decisions – depending on real-time conditions – to keep electricity flowing smoothly and safely.

Ex-ante assessment

An evaluation of something that is considered, evaluated or decided before an event or action takes place based on predictions, assumptions or available information at that time. It involves looking forward and anticipating potential outcomes, rather than analysing what has already happened. Source: <https://lsd.law/define/ex-ante>

Ex-post assessment

An evaluation of the impact of an intervention (such as a policy, programme or regulation) after it has been implemented and has been in operation for a period of time. It is based on actual results, rather than anticipated results (which are considered as part of ex-ante assessment work). Source: <https://definitions.lsd.law/ex-post>

Expert judgement

A technique in which judgement is provided based on a specific set of criteria and/or expertise that has been acquired in a specific knowledge, application, or product area, or in a particular discipline or industry. Source: www.projectmanagement.com/wikis/344587/expert-judgment

F

Feed-in tariff (FiT)/feed-in premium

A policy that typically guarantees renewable generators specified payments per unit (e.g., US\$ per kWh) over a fixed period. FiT policies also may establish regulations by which generators can interconnect and sell power to the grid. Numerous options exist for defining the level of incentive, such as whether the payment is structured as a guaranteed minimum price (e.g., an FiT), or whether it floats on top of the wholesale electricity price (e.g., a feed-in premium).

Fossil fuel displacement

The deliberate, systematic retirement and replacement of electricity generation capacity based on coal, natural gas, and oil with renewable, zero-emission, or low-carbon energy sources. Source: <https://energy.sustainability-directory.com/area/fossil-fuel-generation-displacement/resource/1>

G

GHG impact

Changes in GHG emissions by GHG sources and carbon pools that result from a policy.

Grid emission factor (GEF)

A measure of the amount of carbon emissions per unit of electricity generated. Source: www.ema.gov.sg/resources/faqs/statistics/carbon-emissions/what-is-grid-emission-factor-gef

Grid stability

The capacity of an electrical power grid to maintain a steady state of operation, particularly when subjected to disturbances. This operational steadiness is crucial for ensuring a consistent and dependable supply of electricity to end users. Source: <https://energy.sustainability-directory.com/area/grid-stability>

I

Impact assessment

The process of identifying the future consequences of a current or proposed action. The ‘impact’ is the difference between what would happen with the action and what would happen without it. Source: <https://iaia.org/wp-content/uploads/2025/03/What-is-Impact-Assessment.pdf>

Internal rate of return (IRR)

The annualized implied discount rate at which the net present value of all cash flows (both inflows and outflows) from a particular investment or project equals zero, from the point in time of the initial capital investment until the end of a defined period. Broadly, the IRR is the notional compound annual interest rate that an investment earns over its lifetime, assuming reinvestment of returns at the same rate. Source: <https://uk.practicallaw.thomsonreuters.com/w-013-6916>

K

Key performance indicators (KPIs)

The critical, quantifiable measures of progress toward a desired result. They help organizations determine if their efforts are making an impact, allocate resources effectively, and focus improvements where they matter most. Source: www.kpi.org/kpi-basics

L

Levelized cost of electricity (LCOE)

The cost per unit of energy from an energy-generating asset that is based on the present value of its total construction and lifetime operating costs, divided by total energy output expected from that asset over its lifetime.

M

Methane (CH₄)

A potent GHG that is the second-largest contributor to Earth's warming after CO₂. Methane comes from both natural sources and human activities. Source: <https://science.nasa.gov/earth/explore/earth-indicators/methane>

Monitoring indicators/key performance indicators (KPIs)

Critical, quantifiable measures of progress towards a desired result. They help organizations to determine the impact of their efforts, allocate resources effectively and focus improvements where they matter most.

N

Nationally determined contributions (NDCs)

National climate action plans by each country under the Paris Agreement. A country's NDC outlines how it plans to reduce GHG emissions to help meet the global goal of limiting temperature rise to 1.5°C and adapt to the impacts of climate change. The Paris Agreement requires that NDCs are updated every five years with increasingly higher ambition, taking into consideration each country's capacity. Source: www.un.org/en/climatechange/all-about-ndcs

P

Policies

Interventions at various stages along a policymaking continuum, from broad strategies that define high-level objectives to specific policy instruments for carrying out strategies or achieving desired outcomes.

Policy instrument

A mechanism utilized by a Government, institution or other entity to carry out policy strategies. It may include laws, regulations, and standards; taxes, charges, subsidies, and incentives; information instruments; voluntary agreements; the implementation of new technologies, processes, or practices; and public or private sector financing and investment.

Policy interactions

The ways in which different policies influence one another and how they collectively impact the intended outcomes of public policy. Source: <https://fiveable.me/key-terms/introduction-to-public-policy/policy-interactions>

Policy scenario

A scenario that represents the events or conditions most likely to occur in the presence of the policy (or package of policies) being assessed. The policy scenario is the same as the baseline scenario, except that it includes the policy (or package of policies) being assessed. Source: www.eea.europa.eu/help/glossary/eea-glossary/intervention-scenario

Power purchase agreement (PPA)

A contract between two parties: one that generates electricity (the seller) and one that is looking to purchase electricity (the buyer).

Project lifetime

The expected operational lifespan of a power project, during which it can reliably generate energy. Source: www.energea.com/glossary/lifetime-project-lifetime

R**Renewable energy (RE)**

RE sources, also called renewables, are energy sources that replenish (or renew) themselves naturally. Typical examples are solar energy, wind and biomass. Source: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Renewable_energy_sources

Renewable electricity generation

The process of converting energy into electricity and/or useful heat from a primary energy source such as wind, solar radiation, biomass, etc.

Resource potential (theoretical, technical, economic)

The amount of energy that can be derived from a renewable resource, defined at different levels. Theoretical potential refers to the total energy content of the resource without constraints. Technical potential represents the share that can be exploited using current technologies, considering physical and technical limitations. Economic potential is the portion of the technical potential that can be developed under prevailing economic, market and policy conditions.

S

Self-generation

The use of power generated on-site by an energy consumer to reduce, at least in part, the purchase of electricity from the grid. Source: www.emissions-euets.com/internal-electricity-market-glossary/1333-self-generation

Solar photovoltaic (PV)

A technology used for converting light directly into electricity. Solar PV cells are constructed from semiconducting materials that use sunlight to separate electrons from atoms to create an electric current. Modules are formed by interconnecting individual cells. Building-integrated PV generates electricity and replaces conventional materials in parts of a building envelope, such as the roof facade.

Stakeholder participation

Involving affected parties in decision-making for better outcomes. Source: <https://esg.sustainability-directory.com/term/stakeholder-participation>

Storage cycle count

The number of times a battery has been fully charged and then fully discharged. One full cycle equals using 100 per cent of the battery's capacity. If only 50 per cent of the battery capacity is used in one day, and then it is charged, and 50 per cent is used the next day, that counts as one cycle. Batteries have a limited lifespan; every cycle causes slight deterioration, and after a certain number of cycles (the 'cycle life'), the battery will no longer hold a useful amount of charge.

Storage round-trip efficiency

The percentage of electricity that one can get back out of a battery compared to the amount of electricity put into it. When charging a battery, some energy is always lost as heat or is used by the battery's own cooling and management systems.

Supervisory control and data acquisition (SCADA)

A system that monitors and controls equipment in power grids, such as substations, transformers and battery systems. It collects data and lets operators manage the grid remotely.

Sustainable development impacts

The positive change created for both environment and society, designed to last. Source: <https://climate.sustainability-directory.com/term/sustainable-development-impact>

T

Tax incentive policy

Plans for reducing taxes for businesses and individuals in exchange for specific desirable actions or investments on their part. Their purpose is to encourage those businesses and individuals to engage in behaviour that is socially responsible and/or benefits the community. Source: <https://unfccc.int/policy/tax-incentives>

Tender policy

- Tender policy: see 'Auction'.

Transformational change

Engagements that help achieve deep, systemic and sustainable change with large-scale impact in an area of global environmental concern. Source: www.adaptation-fund.org/wp-content/uploads/2025/06/MCFs-Transformational-Change_220525_3.pdf

Transmission constraints

Limitations in the capacity of power lines or grid infrastructure that restrict the flow of electricity between locations, often causing price spikes or supply issues in affected areas. Source: www.enverus.com/glossary/transmission-constraints

V

Variable renewable energy (VRE)

An RE source that fluctuates within a relatively short time frame, such as wind and solar energy, which vary within daily, hourly, and even subhourly time frames. By contrast, resources and technologies that are variable on an annual or seasonal basis due to environmental changes, such as hydropower (due to changes in rainfall) and thermal power plants (due to changes in temperature of ambient air and cooling water), do not fall into this category

VRE grid integration

Connecting various VRE sources like solar and wind farms to the existing electrical grid in a way that is stable, reliable and beneficial for the majority of people. Source: <https://energy.sustainability-directory.com/term/vre-grid-integration>

W

Weighted average cost of capital (WACC)

The average cost at which the project secures funding from all its sources. Source: www.adb.org/sites/default/files/institutional-document/535126/financial-analysis-evaluation-guidance-note.pdf

Wind power/energy (onshore/offshore)

A form of RE that harnesses the power of the wind to generate electricity. It involves using wind turbines to convert the turning motion of blades, pushed by moving air (kinetic energy), into electrical energy (electricity). Source: <https://windexchange.energy.gov/what-is-wind>

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