7 Estimating renewable energy addition of the policy ex-ante

This chapter provides a method for the first step of ex-ante impact assessment: estimating the RE addition that the policy can be expected to achieve. RE addition refers to the additional installation of RE capacity or electricity generation from renewable sources realized via the policy, expressed in megawatts or megawatt-hours, respectively. The expected RE addition depends on a number of factors, which are accounted for in this chapter.

Checklist of key recommendations

- 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

7.1 Introduction to estimating renewable energy addition

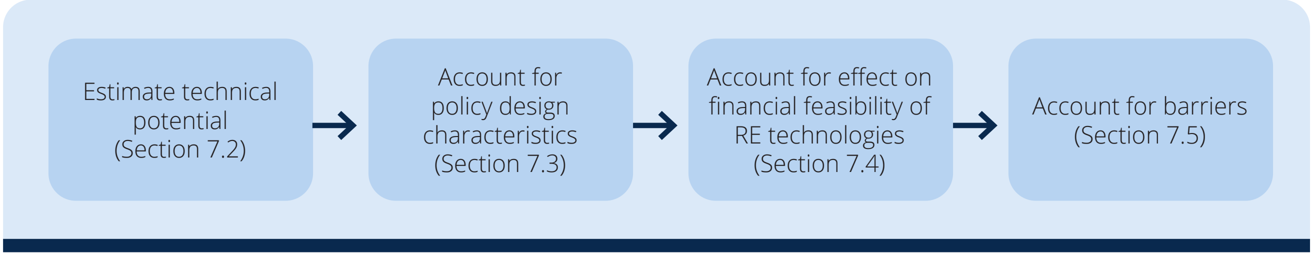
There are four steps to estimating the RE addition of the policy:

- estimate the technical potential of the policy for the assessment period
- account for policy design characteristics that influence the technical potential, such as the scope of eligibility, differentiation between technologies, payment structure, longevity of financial support, and complexity of regulatory and legal procedures
- identify factors that affect the financial feasibility of RE technologies and account for their effect on the technical potential for the assessment period (including accounting for alternative cost considerations, other policies in the sector and sector trends)
- identify other barriers that are not addressed by the policy and account for their effect on the technical potential for the assessment period.

Once these four steps are complete, users may wish to conduct a plausibility check by undertaking a benchmarking exercise. Because similar policies in similar countries often yield similar results, countries can compare their RE addition estimates with results from similar countries to ascertain whether the

FIGURE **7.1**

Overview of steps in the chapter



estimated RE addition seems reasonable. Users can refer to reports such as the REN21 Renewables Global Status Reports[19] for an overview of countries that have implemented similar policies. Where this benchmarking exercise shows significant discrepancies (between the estimated RE addition and results from other countries and policies) that cannot be easily explained, users should revisit the inputs and method used to estimate the RE addition, in an effort to refine the estimated RE addition.

Appendix C provides country examples for each of the three types of policies covered by this methodology. These are examples only, and users should use other peer country case studies that serve as appropriate benchmarks for their country context and specific policies.

7.2 Estimate the technical potential for the assessment period

The first step in estimating the RE addition resulting from the policy is to estimate the technical potential for the assessment period of the policy. In this methodology, the technical potential is defined as in the IPCC *Special Report on Renewable Energy Sources and Climate Change Mitigation*[20] (unless otherwise noted):

> Technical potential is the amount of renewable energy output obtainable by full implementation of demonstrated technologies or practices. No explicit reference to costs, barriers or policies is made. Technical potentials reported in the literature being assessed in this report, however, may have taken into account practical constraints and when explicitly stated there, they are generally indicated in the underlying report.

The users of this methodology can refer to other “potential” definitions, where relevant or useful. Box 7.1 provides a few of the most relevant definitions of different potentials.

Figure 7.2 shows three examples of how policy caps on annual capacity limits might determine the technical potential for the assessment period. A policy cap is a volume-based cap (e.g. on additional capacity installed or electricity generated) or price-based threshold (e.g. on which the support levels are determined) to set limits on policy costs.[21] In this methodology, the term “policy cap” refers to the maximum quantity of installed capacity supported by the policy for illustration purposes, unless otherwise noted.

Depending on the particular policy case, users may need to conduct additional analysis to identify the potential that is technically feasible to deploy to the end of the assessment period for a particular policy.

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), users estimate the technical potential using available information, such as scenario studies or databases on RE resource potentials.

7.2.1 Case I: policy with cap set for entire assessment period

For feed-in tariff policies, it is an increasingly common practice to set a cap, either at a maximum of RE addition per year or over the lifetime of the policy. Policy caps are implicit in the design of auctions and tenders, as a certain quantity is tendered and thus serves as the cap on either the number of installations, megawatts installed or electricity generated. A policy cap can be set on a periodic, annual or even monthly basis.

As shown in Figure 7.3, the aggregated periodic/annual/monthly policy caps determine the starting point of the user’s analysis to estimate the addition of RE capacity over the entire assessment period (1,000 MW of RE addition, in this example). This is based on the underlying assumption that no further RE addition beyond the periodic/annual/monthly caps is supported by a given policy.

Users might reconsider using the aggregated periodic/annual/monthly cap to estimate the addition of RE capacity over the entire assessment period in the following cases:

- The policy cap is indicative and non-binding. In this case, users should carefully assess whether to use the aggregated non-binding cap to estimate the addition of RE capacity over the entire assessment period.

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[19] Available at: www.ren21.net/status-of-renewables/global-status-report.

[20] Available at: www.ipcc.ch/report/renewable-energy-sources-and-climate-change-mitigation.

[21] Fruhmann (2015).

BOX **7.1**

Definition of renewable energy supply "potentials" other than the IPCC definition of "technical potential"

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.

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.

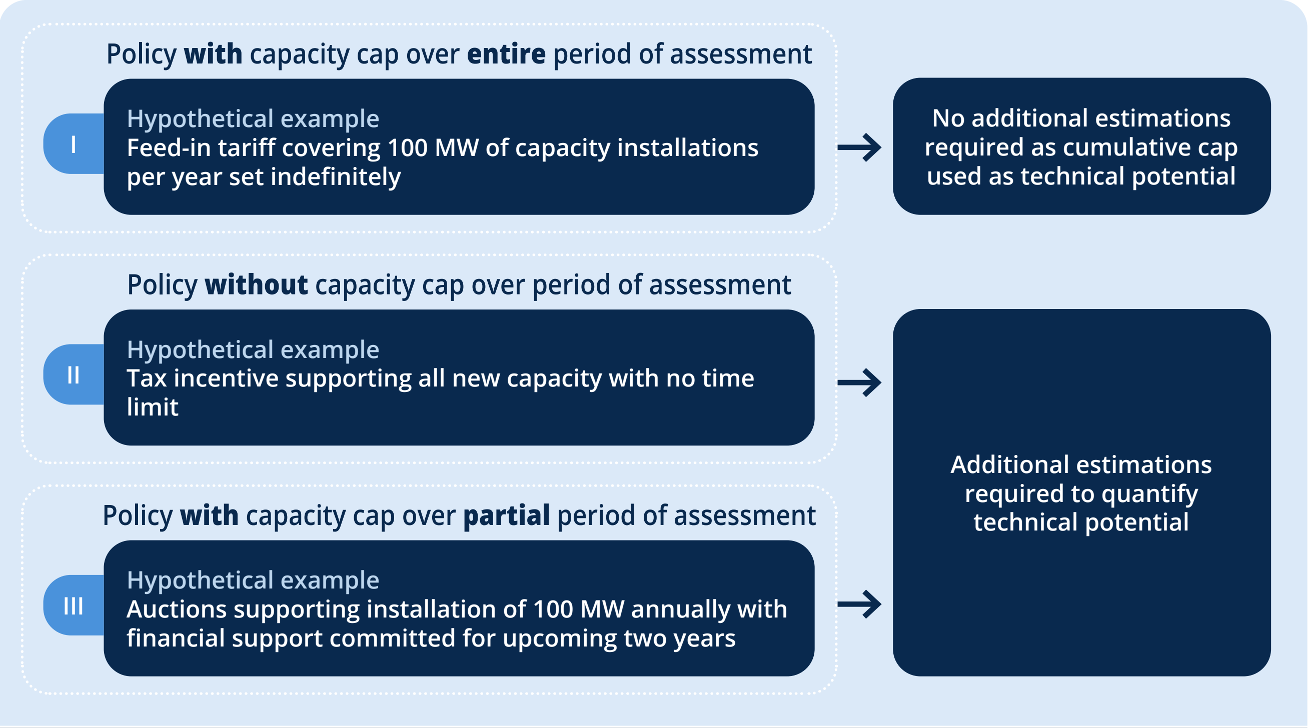
Economic potential is the amount of RE output projected when all social costs and benefits related to that output are included, there is full transparency of information, and it is assumed that exchanges in the economy install a general equilibrium characterized by spatial and temporal efficiency. Negative externalities and co-benefits of all energy uses and other economic activities are priced. Social discount rates 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: IPCC 2012.

FIGURE **7.2**

Three policy cases and their implications for determining the technical potential for the assessment period



Alternatively, users may follow the approach to quantifying the technical potential for the assessment period for RE policies without a cap described in Section 7.2.2.

- The policy cap is binding, but there is still potential for the policy to exceed its objective if the government decides to revise the cap. In this instance, the starting point to estimate the addition of RE capacity over the entire assessment period is still the policy cap, which might need to be adapted if the policy cap is revised. For example, a government may decide to set an artificially low cap in the beginning, when experience with the technology is lacking or where the government has decided against further deployment. As technology penetration grows, acceptance and trust may increase, leading the government to revise the RE policy cap upwards.

7.2.2 Case II: policy without cap set for entire assessment period

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 7.4 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 these options help estimate the resource potential and not the technical potential during the assessment period. Preference should be given to the quality of the data or study.

FIGURE **7.3**

Case I – policy with cap set for entire assessment period

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	
100 MW	100 MW	100 MW	100 MW	100 MW	1,000 MW

FIGURE **7.4**

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

Abbreviation: -, not applicable

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 use.

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. Table 7.1 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[22] published by the Secretariat of Energy 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,[23] 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, ranging from "technical potential" to "theoretical potential" and "economic potential", as per the IPCC definition,[24] and break them down into national or regional levels. Users should use caution when referring to the "potential" values presented in these studies and how to make use of them in the assessment.

TABLE **7.1**

Examples of available country-specific studies for national renewable energy 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),[a] Indonesia,[b] Russia,[c] south-east Europe,[d] Egypt[e] and others	Studies on renewable energy 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	138 countries[f]	Provides a vision for the transition to 100% wind, hydro and solar energy by 2050.
Global Wind Energy Council	Wind	80 countries (e.g. United States, all the European markets, India, China)	Provides country reports with (technical) potentials.

[a] IRENA (2014).
[b] IRENA (2017a).
[c] IRENA (2017b).
[d] IRENA, Joanneum Research and University of Ljubljana (2017).
[e] IRENA (2018a).
[f] https://thesolutionsproject.org/why-clean-energy/#/map/countries/

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[22] Available at: https://dgel.energia.gob.mx/azel/

[23] Available at: https://irena.masdar.ac.ae/gallery/#gallery.

[24] IPCC (2011).

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

A number of 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. Table 7.2 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.

TABLE **7.2**

Examples of databases on renewable energy resource availability

Name of database	Private or public	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
IRENA Global Atlas for Renewable Energy[a]	Public (a free login is required to see all available maps)	Wind, solar, geothermal, biomass, ocean, hydro	All countries	A web platform coordinated by IRENA that allows users to find maps of RE resources for locations around the globe. It provides datasets, expertise and financial support to evaluate national RE potentials.	Both
NREL and USAID Renewable Energy Data Explorer (REexplorer)[b]	Public	Biomass, geothermal, hydro, solar, wave, wind	Afghanistan, Bangladesh, Central Asia, Colombia, Ghana, India, Kenya, Mexico, Nepal, Pakistan, Peru, South-East Asia (including Brunei Darussalam, Burma, Cambodia, Indonesia, Lao PDR, Malaysia, Philippines, Singapore, Thailand and Vietnam)	REexplorer provides RE data, analytical tools and technical assistance to developers, policymakers, and decision makers in developing countries. REexplorer can be used to analyse and visualize RE potential (estimated through hourly data and geospatial variables) under user-defined system scenarios.	Both
NASA Prediction of Renewable Energy Resources (POWER)[c]	Public	Wind, solar	All countries	NASA provides solar and meteorological data sets from NASA research for support of RE, building energy efficiency and agricultural needs in its POWER programme. Data are accessible by multilayer maps, and up to 20 different parameters can be selected.	Both

TABLE **7.2,** continued

Examples of databases on renewable energy resource availability

Name of database	Private or public	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
Renewables.ninja[d]	Public	Wind, solar	All countries	Renewables.ninja allows users to run simulations of the hourly power output from wind and solar. It can find past yields and predict yields in specific locations.	RE potential
PVWatts[e]	Public	Solar PV	Americas, Indian subcontinent, parts of Central Asia	PVWatts Calculator is an online free tool developed by NREL to estimate the energy production and cost of energy for grid-connected solar PV.	RE potential
PV Sol[f]	Public	Solar PV	Not specified	PV Sol is an online free tool that estimates the optimal connection of the PV module and the best-suited inverter. It also simulates the annual PV energy and performance ratio. A more extensive software tool can be purchased online.	Both
PVGIS[g]	Public	Solar PV	Europe, Africa, Americas, Asia	PVGIS is an online free tool to estimate the electricity yield of a PV system. It was developed by the Joint Research Centre from the European Commission. It gives the annual and monthly power production based on site and module specifics. The results can be visualized online or downloaded in CSV format.	Both
WindSim[h]	Public	Wind	Not specified	WindSim is used for wind farm optimization by identifying turbine locations with the highest wind speeds, to maximize power production. It uses computational fluid dynamics and 3D models of the terrain to obtain the optimized wind park layout.	RE potential
Global Energy Resources Database (Shell)[i]	Public	Solar (distributed, centralized), wind (offshore, onshore), biomass, hydro, geothermal	All countries	Provides a long-term energy production potential by 2070 (data per country and technology in energy units/year – not as a time series). How this potential is calculated is not specified.	RE potential

TABLE **7.2,** continued

Examples of databases on renewable energy resource availability

Name of database	Private or public	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
pvPlanner[j]	Public (1 month free trial) Private (after 1 month)	Solar PV	All countries (time period availability varies per country)	pvPlanner simulates PV electricity production by models developed by Solargis. It uses technical and site parameters as input and provides electricity yield, solar-in-plan irradiation and performance ratio as output. The site parameters are based on long-term annual and monthly averages. The output is delivered in PDF, XLS or CSV format.	Both
AWS Truepower's Windographer[k]	Private	Wind	Depends on the data imported. It supports all formats.	The software from Windographer can be purchased and downloaded online. It imports wind data of any kind and makes it easy to analyse. The data can be visualized, and errors can be automatically detected. The software provides several output layouts.	Both
Wind Atlas Analysis and Application Program (WAsP) from Risoe National Laboratory[l]	Private	Wind	All countries	WAsP is a software tool for wind resource assessment for single wind turbines and wind farms. It includes features for different terrains, climatic stability on site and more. The outputs consist of energy yield, wind farm efficiency, turbulence mapping and site assessment.	RE potential
PVSyst[m]	Private	Solar PV	Not specified	PVSyst provides a software tool that allows users to analyse PV technology yields, based on different configurations. The goal is to develop an optimal and reliable PV system. The software can be purchased and downloaded from PVSyst's website.	Both
3TIER Dashboard (Vaisala)[n]	Private	Wind, solar	Not specified	3TIER is a web-based application that allows users to access renewable resource data for wind (e.g. wind speed at different heights) and solar (e.g. solar irradiation).	Data for RE calculation

TABLE **7.2,** continued

Examples of databases on renewable energy resource availability

Name of database	Private or public	Technology coverage	Geographic coverage	Main description	RE potential or data for RE potential calculation
AWS Truepower (UL Renewables)[o]	Private	Wind	All countries	The Wind Resource Grids provided by AWS Truepower through Windnavigator allow users to site meteorological towers, design preliminary layouts and obtain preliminary estimates of the wind energy generated for small to multi-turbine wind projects.	Both
SolarGIS[p]	Private	Solar PV	All countries	SolarGIS provides solar electricity data that are used in the whole life cycle of solar power plants, from prospecting to development and operation.	Both
Meteonorm[q]	Private	Solar PV	All countries (time period availability varies per country)	Meteonorm's software provides solar radiation data and calculation tools to estimate solar PV power yields. The data are obtained from weather stations worldwide and include many parameters. After purchase, the tools are available as a web service or on desktop.	Both

Abbreviations: NASA, National Aeronautics and Space Administration; NREL, National Renewable Energy Laboratory; PV, photovoltaic; USAID, United States Agency for International Development

[a] http://irena.masdar.ac.ae

[b] www.re-explorer.org

[c] https://power.larc.nasa.gov/data-access-viewer

[d] www.renewables.ninja

[e] https://pvwatts.nrel.gov

[f] http://pvsol-online.valentin-software.com/#/

[g] http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

[h] https://windsim.com

[i] www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenarios-energy-models/energy-resource-database.html

[j] https://solargis.info/pvplanner/#tl=Google:hybrid&bm=satellite

[k] www.windographer.com

[l] www.wasp.dk

[m] www.pvsyst.com

[n] www.3tier.com/account/login/?next=/dashboard

[o] https://aws-dewi.ul.com

[p] https://solargis.com

[q] https://meteonorm.com/en

Table 7.3 provides examples of methodologies and tools that can be used to estimate the RE potential using input data available in databases listed in Table 7.2.

To do so, users need to first consider resource factors related to the availability of RE sources, including:

- physical constraints – physical characteristics that determine or constrain the overall potential for RE extraction, such as total sun hours in a country or region
- energy content of resource – energy content that can theoretically be converted into electricity, such as wind intensity profile or solar radiation intensity
- theoretical physical potential – maximum potential of RE extraction depending on the physical characteristics and energy content of the resource.

For countries where neither national studies (option 1) nor data from international databases (option 2) are available, the user can collect local or national data. These data can be obtained from national experts (e.g. in-house experts in ministries, research groups at national universities or other research organizations, local consultants) or be informed by available data from other countries in the region that share similar circumstances. Users should look at parameters provided by the databases in Table 7.2 and the tools presented in Table 7.3 that describe calculation steps for RE potential, and list data and parameters needed for calculations. In general, users should be aware that this user-driven data-collection approach might be very time- and resource-intensive. Expert input and review should be involved at all stages.

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

RE potential studies and databases presented in options 1 and 2 may only provide data on the RE resource potential. This is useful to quantify the long-term technical potential, but not the technical potential for the assessment period considered for the policy in question. In such cases, users may need to quantify the technical potential for the final year of the assessment period.

Quantification of the potential for the final year of the assessment period can be done by interpolating between the current installed capacity (or generation) and the long-term technical potential. This quantification should be done for each RE technology type. The results for each are then aggregated to obtain the total technical potential.

Users may need to make a number of assumptions to quantify the potential for a specific year, including:

- the long-term target year in which the long-term technical potential could be achieved
- the shape of the RE deployment trajectory – it can be linear, S-shaped or any other shape that the user considers realistic.

Once the RE technical potential for the final year of the assessment period is estimated, it is important to examine whether the annual growth rates in installed capacity, amount of electricity generated and share of electricity generation can be considered reasonable. For example, the IRENA database on Trends in Renewable Energy[25] provides necessary data to compare historical annual growth rates for specific technologies with the technical potential for the assessment period estimated by the user. This step will ensure robustness of obtained results and underlying assumptions.

It is also important to take into account the time required to build RE power plants. Construction of RE capacity, and therefore realization of the RE potential, takes time. Users should estimate the technical potential for the assessment period taking into account the time it takes to install RE capacity and how much capacity can practically be installed within the relevant time frame – that is, assuming no constraints imposed by policy design characteristics, economic and financial factors, and other barriers. Table 7.4 provides an overview of technology lead times from literature. Users should consider such lead times when making or cross-checking assumptions on the uptake of RE technologies.

7.2.3 Case III: policy with cap set for a portion of the assessment period

In some cases, the time frame associated with the policy cap does not match the assessment period. Figure 7.5 provides an example of an RE policy that has a shorter financial commitment from the government than the assessment period. In this case, the cap covers the first two years of the policy, while

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[25] IRENA (2019b).

TABLE **7.3**

Support tools to estimate renewable energy 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 (m^2) • Solar panel yield or efficiency (%) • 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
Solar PV	• System size (kW, DC) • Module type (std, medium, thin film) • System losses (%) • 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 (%)	The methodology behind PVWatts calculations (see Table 7.2) can be applied to data outside the PVWatts calculator. The methodology is available from the PVWatts manual (Dobos, 2013, 2014).	Medium
Wind	• ρ = air density (kg/m^3) • A = rotor swept area (m^2) • Cp = coefficient of performance • V = wind velocity (m/s) • Ng = generator efficiency • Nb = gear box bearing efficiency	Several websites or papers available (e.g. MIT; Sarkar and Behera [2012]; Windpowerengineering.com)	Low
Biomass electricity	Depends on desired output	CDM methodologies: • *AM0007: Analysis of the Least-Cost Fuel Option for Seasonally-Operating Biomass Cogeneration Plants* • *ACM0006: Consolidated Methodology for Electricity and Heat Generation from Biomass* • *ACM0018: Electricity Generation from Biomass Residues in Power-Only Plants* • *ACM0020: Co-Firing of Biomass Residues for Heat Generation and/or Electricity Generation in Grid Connected Power Plants*	
Geothermal	Depends on desired output, but most important are: • surface temperature • heat flow • density of earth material • depth of heat source	Beardsmore et al. (2010)	Medium

TABLE **7.4**

Project lead times for renewable energy technologies

Technology	Lead time	References
Solar PV	Single rooftop: 1 day – 1 week 5–100 MW solar farms: 4–12 months >100 MW solar farms: 12–36 months	SEIA (2019) Sovacool, Gilbert and Nugent (2014) Sovacool, Nugent and Gilbert (2014) International Finance Corporation (2015)
CSP	12–36 months	Sovacool, Gilbert and Nugent (2014) Sovacool, Nugent and Gilbert (2014)
Wind	Up to 10 MW farms: 2 months Up to 50 MW farms: 6 months Contemporary average (including offshore): 12 months Offshore potential per wind turbine: 2–3 days	Sovacool, Gilbert and Nugent (2014) Sovacool, Nugent and Gilbert (2014) EWEA (2016) IRENA (2012a)
Biomass	18–57 months	Ministry of New and Renewable Energy India (2019) U.S. Energy Information Administration (2019) Sovacool, Gilbert and Nugent (2014)
Geothermal	3–5 years	Budisulistyo and Krumdieck (2015) Shortall, Davidsdottir and Axelsson (2015)

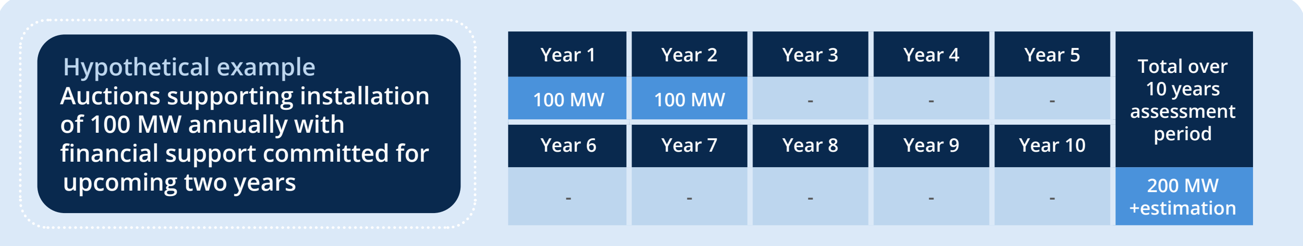
Abbreviation: CSP, concentrated solar power

the assessment considers impacts over a 10-year time frame.

In such cases, quantification of the technical potential for the assessment period may require a few considerations in addition to those described in Section 7.2.2. For example, would the policy cap for the first years lead to lock-in of a certain infrastructure that negatively affects the technical potential of the RE technologies in question? Is there a short-term need for electricity generation that will not be met through the policy to promote RE

FIGURE **7.5**

Case III – policy with cap set for a portion of the assessment period



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

Abbreviation: -, not applicable

and thus lead to the construction of large fossil fuel generation plants?

Users should use caution when determining which assumptions are realistic given the country- and policy-specific circumstances, and transparently explain all assumptions made.

7.2.4 Examples of estimating technical potential for the assessment period

The examples below illustrate how RE addition would be calculated for two types of policies – auctions (example 1) and feed-in tariff (example 2) – taking into account the various factors that need to be considered to establish a credible figure. The examples are presented in a stepwise approach to illustrate the four steps needed to develop a final estimate. Step 1 is shown in Boxes 7.2 and 7.3.

It is important to note that the examples presented relate to increases in RE generation capacity (i.e. MW) for purposes of illustration and simplicity, even though many policies, including auctions and feed-in tariffs, support the purchase of electricity (i.e. MWh). Capacity factors, which are used to calculate electricity generated from installed capacity, are introduced in Chapter 8.

BOX **7.2**

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 has 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 from 2020 to 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 cap set for a portion of the assessment period** (in Section 7.2.3).

The user refers to the total specified tendered capacities of 150 MW between 2020 and 2022 as a starting point, while making an informed additional assumption for the period between 2023 and 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 rate 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

BOX **7.3**

Feed-in tariff (example 2) – estimating technical potential for the assessment period for a feed-in tariff 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** (in Section 7.2.2).

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:

- 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

7.3 Account for policy design characteristics

Several design characteristics common to RE policies influence their impact. These include the scope of eligibility, differentiation between technologies, payment structure, longevity of financial support, and complexity of regulatory and legal procedures. It is a *key recommendation* to identify policy design characteristics and account for their effect on the technical potential for the assessment period of the policy.

Tables 7.5–7.7 list the main design characteristics for the three different types of RE policies and describe how each influences the technical potential for the assessment period. Specifically, Table 7.5 presents design characteristics for feed-in tariffs, Table 7.6 presents design characteristic for auction policies, and Table 7.7 presents design characteristics for tax incentives.

Users should use these tables to:

- identify design characteristics that are likely to influence the RE technical potential in their country context
- describe how the identified policy design characteristics are expected to influence RE deployment
- estimate the overall influence of these characteristics on the RE technical potential for the assessment period of the policy.

TABLE **7.5**

Feed-in tariff policies – influence of policy design characteristics on technical potential for the assessment period

Design characteristic	Description	Influence on technical potential for the assessment period
Eligibility	• Project owner • Technology • Size • Location	• The narrower the eligibility conditions of the feed-in tariff policy, the lower the probability that the policy achieves its 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 levelized cost of electricity 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 feed-in tariff 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 feed-in tariff 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 feed-in tariff 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.
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 feed-in tariff. 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.

TABLE **7.5,** continued

Feed-in tariff policies – influence of policy design characteristics on technical potential for the assessment period

Design characteristic	Description	Influence on technical potential for the assessment period
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 feed-in tariff 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); UNEP (2012); UNESCAP (2012).

TABLE **7.6**

Auction policies – influence of policy design characteristics on technical potential for the assessment period

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.

TABLE **7.6, continued**

Auction policies – influence of policy design characteristics on technical potential for the assessment period

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 seal-bid or descending clock auction) 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.
Sellers' contractual liability requirements	• Commitments to contract signing • Contract schedule • Remuneration profile and financial risks • Nature of the quantity liabilities • Settlement rules and underperformance penalties • Delay and underbuilding penalties	• High overall liability requirements may deter potential bidders, possibly decreasing the likelihood that the technical potential for the assessment period is achieved. • The less predictable and stable the institutional and regulatory framework, the higher bidders' perceived risk in the auctioning process and the lower the probability that the technical potential for the assessment period is achieved. • The lack of sellers' liability requirements provides an incentive for drastic underbidding, lowering the probability that the technical potential for the assessment period is achieved.

Sources: Adapted from IRENA (2013, 2015a); Agora Energiewende (2014).
Abbreviation: PPA, power purchase agreement

TABLE **7.7**

Tax incentive policies – influence of policy design characteristics on technical potential for the assessment period

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 low level of incentives lower the probability that the technical potential for the assessment period is achieved.

TABLE **7.7**, continued

Tax incentive policies – influence of policy design characteristics on technical potential for the assessment period

Design characteristic	Description	Influence on technical potential for the assessment period
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 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); IRENA (2015b).

To estimate the overall influence of each policy characteristic on the technical potential for the assessment period of the policy, users can follow the following steps:

1. Make a first order estimate of how each policy design characteristic might influence the expected RE addition for the assessment period. Depending on the type of design characteristics, this can be done by specifying a total capacity value to be deducted (e.g. 200 MW from the entire potential) or a percentage factor (e.g. 5% of the entire potential) to be applied to the expected RE addition of the policy for the assessment period. This first order estimate can be informed by previous experience with other policies (in-country or external) or literature in the field.

2. Consult with stakeholders and/or experts (e.g. experts in power systems, electricity sector policy or electricity grids) to validate and, where necessary, revise the first order estimates. In case of high uncertainty and diverging expert opinions, users could also apply an uncertainty range to indicate this difference in judgment (e.g. 150–200 MW or 5–10%).

3. Deduct the first order estimates from the technical potential for the assessment period to reflect the impact of policy design characteristics.

7.3.1 Examples to account for policy design characteristics

BOX **7.4**

Auctions (example 1) – using policy design characteristics to refine expected renewable energy addition for the assessment period

1. **Estimate technical potential for the assessment period** (from Box 7.2) – **640 MW**

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 power purchase agreement (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

BOX **7.5**

Feed-in tariff (example 2) – using policy design characteristics to refine expected renewable energy addition for the assessment period

1. Estimate technical potential for the assessment period (from Box 7.3) – **1,300 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

7.4 Account for effect on financial feasibility of renewable energy technologies

RE policies can provide financial incentives that directly influence the financial feasibility of RE technologies and, in turn, the expected RE addition of the policy for the assessment period. It is a *key recommendation* to 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. Existing cost–benefit analyses (e.g. conducted in the policy design phase) should be used as a basis here and should be updated as needed.

In this step, users make an initial estimate of the effect of the policy on the financial feasibility of RE technologies (Section 7.4.1). Users should then account for alternative cost considerations, other policies in the sector and sector trends. The effect of financial barriers on the expected RE addition of the policy for the assessment period is considered separately in the barrier analysis (Section 7.5).

7.4.1 Identify factors that affect the financial feasibility of renewable energy technologies

Users should identify the level of incentive provided by the policy and its effect on the financial feasibility of RE technologies. Where possible, they should build upon existing cost–benefit analyses. The cost–benefit analyses should be updated to reflect recent developments, and confirm their continued applicability and completeness.

A number of factors need to be considered. First are factors that are directly related to RE deployment, including the following:

- **Cost of the technology in the local market** – includes capital costs, operations and maintenance costs, and fuel (e.g. biomass) costs. Mark-ups may arise in local markets as a result of inexperience with a given technology in the country – for example, a shortage of engineers that necessitates bringing in outside expertise. Technology costs in local markets can also be driven by advances in knowledge, which reduce technology costs over time.

- **Technical characteristics of the technology applied in the local market** – include capacity of the technology, load characteristics and operational lifetime of the technology.

- **Project financing** – includes financing sources and their conditions, such as interest rates and duration of loans. Project finance generally comes in three forms: equity, private debt and public debt financing. These can be captured in the weighted average cost of capital (WACC), which is the rate a company is expected to pay, on average, to compensate all its investors. The formula for calculating the WACC is provided in Appendix B.

- **Rate of return considerations by financiers/investors** – the internal rate of return (IRR) is the compounded annual rate of return a project is expected to generate over time.[26] The IRR is the discount rate at which the net present value of the project is zero (i.e. the average discount rate at which the cash benefits and costs of a project over time are exactly equal).

Second are a number of factors related to the electricity market, including the following:

- **Cost and technical characteristics of alternative technologies** – includes capital costs, operations and maintenance costs, and fuel costs of fossil fuel and nuclear power plants.

- **Electricity price in the local market** – the wholesale market price is the price power producers receive for selling electricity to the grid. The price depends on the type of market and the time when the electricity will feed into the grid.[27] It can also be a price that is agreed directly between two parties, independently of an exchange body supervising the trade (over-the-counter).

- **Variations in the RE resource potential** – RE resource potentials vary widely across regions and different locations. For example, wind resources may be higher in some parts of the country than others; this directly influences wind turbine load capacity and therefore financial feasibility.

The combination of these factors determines how financially feasible RE technologies are in a given country context. The following data sources, prioritized from top to bottom, may be

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[26] Jeffery (2014).

[27] Next Kraftwerke (2016).

useful in determining the financial feasibility of RE technologies:

- calculations made during policy set-up
- national cost studies (e.g. from low emissions development strategies)
- global cost estimates (e.g. from the IRENA RE technology costs with a country-specific resolution[28]).

7.4.2 Evaluate financial feasibility of RE 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 "levelized cost of electricity" (LCOE), a commonly used metric for comparing costs across different power-generating 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 analyse the financial feasibility of different technologies. As a result, the LCOE is often taken as a proxy for the average price that an energy project must receive in a market to break even over its lifetime.

Appendix A provides further information on how to calculate the LCOE. Users can also refer to publicly available LCOE quantification tools (e.g. the Excel spreadsheet tool provided by Agora Energiewende[29]), the GACMO tool of the United Nations Environment Programme and the Technical University of Denmark,[30] or development tools tailored to country-specific circumstances. In some country contexts, users can use more sophisticated LCOE tools – for example, to assess financial de-risking policy options (using the Derisking Renewable Energy Investment methodology of the United Nations Development Programme[31]). Other methods used by public and private investors, and policymakers can also be used in this context.

The financial feasibility of technologies can be estimated by comparing the LCOE for the given RE technology with either the policy's tariff rate (for feed-in tariff and auction policies) or the generation costs of technologies that will be displaced by the RE technology (for tax incentive 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 WACC (see Appendix B) underlying the LCOE with the IRR to evaluate the profitability of a project. In general, the IRR for a given project needs to be equal to or greater than the WACC if the project is to be profitable (i.e. positive net present value).[32] Companies often set a minimum acceptable IRR before investing in a project.

Step 2: Compare the LCOE with financial incentives provided by renewable energy policies

By comparing the LCOE for a given technology and location with the financial incentive provided by the RE policy, users can evaluate whether the policy

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[28] Available at: www.irena.org/costs.

[29] Available at: www.agora-energiewende.de/en/publications/calculator-of-levelized-cost-of-electricity-for-power-generation-technologies.

[30] Available at: www.cdmpipeline.org/.

[31] Available at: www.undp.org/content/undp/en/home/librarypage/environment-energy/low_emission_climateresilientdevelopment/derisking-renewable-energy-investment.html.

[32] Belyadi, Fathi and Belyadi (2017).

makes investment in RE technologies financially feasible.

In the absence of an RE policy, users would normally compare the LCOE with the price they could negotiate in an over-the-counter contract or the (average) wholesale market price of electricity in the market they would sell into. The term "wholesale market price" refers to a more complex situation. In reality, the wholesale market price depends on the particular situation in the country that dictates specific market prices with which RE technologies have to compete. The price depends on the type of market, but also on the time when the electricity will feed into the grid. In many countries, the technology will have to compete with several different prices, depending on the time when the electricity is fed into the grid and how far in advance the price will be set, among other things. An electricity wholesale market price that represents an average price should be chosen.

When evaluating the impact of an RE policy on the financial feasibility of RE technologies, users should combine the LCOE of the particular technology with the financial incentive provided by the policy, and compare that with the electricity wholesale market price (or a combination of prices in the case of premium policies). Possible conclusions that can be drawn from this step of the assessment include the following:

- **LCOE > electricity tariff or wholesale market price.** Where a given RE technology has higher costs, on average, than the tariff or wholesale market price chosen, or financial incentives provided by the policy, the technology is likely to diffuse only in niches. If no such niches exist, the technology is not likely to diffuse at all.

- **LCOE < electricity tariff or wholesale market price.** Where a given technology has lower costs, on average, than the costs of current technologies or financial incentives provided by the RE policy, the technology is likely to diffuse. For these calculations, users can assume that the financial analysis does not further restrict the technical potential for the assessment period of the policy.

- **LCOE < electricity tariff or wholesale market price for certain financing options, or a limited number of projects only.** The technology may only be feasible for a limited number of cases (e.g. only for wind sites with a wind speed higher than a certain threshold).

Users should use caution when making comparisons between calculated LCOE and feed-in-tariffs or power purchase agreement prices because 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 *Renewable Power Generation Costs in 2017* report presents two examples of how such factors can affect the results of the analysis when comparing the LCOE with an electricity tariff, given country- and context-specific circumstances (see Box 1 in the report).[33] In general, users should always aim to consult with national or international experts to discuss the methodological approach chosen and the underlying assumptions.

Users evaluating tax incentive policies can account for such policies' financial implications by including a tax factor in their LCOE calculations that quantifies the impact of income taxes, the depreciation tax shield and investment tax credits. This tax factor includes the investment tax credit, 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 production tax credit (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 investment tax credits (ITCs) and PTCs can be found in *Levelized Cost of Electricity Calculator: a User Guide* by Stanford Graduate School of Business (using ITCs and PTCs in the United States as an example).[34] Alternatively, a methodology developed by the Pontificia Universidad Javeriana Colombia in its publication *Effects of Incentives for Renewable Energy in Colombia* provides detailed guidance on how to incorporate tax deductions on the investment and accelerated depreciation on assets into LCOE calculations.[35]

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[33] Available at: www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.

[34] Available at: http://stanford.edu/dept/gsb_circle/cgi-bin/sustainableEnergy/GSB_LCOE_User%20Guide_0517.pdf.

[35] Available at: www.redalyc.org/articulo.oa?id=47751131007.

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 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.

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, for the consumption of electricity from the grid.

These end-consumer prices can be well above the electricity wholesale market price because they include transmission, distribution and system costs. 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 or without feed-in tariff or tax incentive).
  - The feasibility of 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 financial feasibility 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 financial feasibility 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 mandatory closing of inefficient plants, and quotas for fuels
- subsidies, such as fossil fuel subsidies, or direct and indirect electricity subsidies.

The guidance provided in Section 5.2.2 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 financial feasibility 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 to 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 financial feasibility of RE technologies in comparison with traditional fossil fuel technologies (e.g. cost reductions of natural gas due to accelerated fracking exploration).

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 financial feasibility of renewables.

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

BOX **7.6**

Auctions (example 1) – using financial factors to refine expected renewable energy addition of the policy for the assessment period

1. **Estimate technical potential for the assessment period** (from Box 7.2) – **640 MW**
2. **Account for policy design characteristics** (from Box 7.4) – **550 MW**
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

BOX **7.7**

Feed-in tariff policy (example 2) – using financial factors to refine expected renewable energy addition of the policy for the assessment period

1. **Estimate technical potential for the assessment period** (from Box 7.3) – **1,300 MW**
2. **Account for policy design characteristics** (from Box 7.5) – **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

7.5 Account for barriers

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.

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.

7.5.1 Step 1: Identify barriers

Table 7.8 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 **7.8**

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	• 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 is 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).
Regulatory and policy uncertainty	• Insufficient clarity and transparency in existing regulations or in the development of new policies	• Lack of transparency in policy set-up of feed-in tariff policy and history of ad hoc changes in regulation increase uncertainty, which discourages market actors from participating in the policy.
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	• Several institutions claim responsibility for implementation of the policy. • Procedures on how to participate in, or receive assistance from, the policy are unclear, which discourages market actors.
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 renewables • Access to market	• 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, which limit access for new market actors. • High import tariffs or domestic content requirements hinder deployment of technologies.
Financial or budgetary	• Absence of adequate funding opportunities and financing products for RE • Financing unreasonably costly for RE technologies • 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, feed-in tariffs)	• Insufficient funding is available in the domestic context as a result of high up-front costs of RE investments. • Substantial concerns about financial solvency of state-owned utilities discourage market actors from using the policy.

TABLE **7.8,** continued

Barrier categories

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	• History of technical problems with grid infrastructure prevents decentralized access of RE to the grid.
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	• Insufficient skilled workers are available for installation of wind turbines.
Public acceptance and environmental	• 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)	• 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.

7.5.2 Step 2: Evaluate severity of barriers

Next, evaluate the severity of barriers using a predefined scale, such as a scale from 1 to 5, with 1 indicating low impact and 5 indicating very severe impact. Barriers that are considered to be very severe are those that entirely inhibit the policy from having any impact. Barriers will most likely inhibit a given aspect of the policy and not the entire policy.

The evaluation can involve document analysis, expert judgment and stakeholder consultations.[36] GIZ suggests two distinct methods to rate different barriers – simultaneous rating and pairwise comparison – which are summarized in Table 7.9. Both methods are based on surveys of experts, which are recommended to be carried out as a series of structured interviews. It is also recommended that the interviews be carried out with at least five experts from the fields of politics, business and finance, and science.[37] For example, users may conduct a survey of a small representative sample of investors to assess the severity of barriers relating to perceived investment risks. This allows users to better quantify the subsequent (negative) impact of a given barrier on the RE capacity to be developed over time.

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[36] Refer to the ICAT *Stakeholder Participation Guide* (Chapter 8) for information on designing and conducting consultations.

[37] Partnership on Transparency in the Paris Agreement (n.d.).

TABLE **7.9**

Brief description of the simultaneous rating and pairwise comparison methods

Method	Description
Simultaneous rating	Experts are asked to give a total score out of 100 to each individual barrier according to the barrier's significance. The ratings of the individual experts are then summarized as averages. If the ratings of the experts deviate significantly from one another, the experts should be asked for their rating again after they have been consulted about the results of the first round of the survey in the form of average values (Delphi survey). The significance of the barriers is then calculated, based on the average of the ratings from the second survey round. A problem with this method is the difficulty of estimating the relative severity of barriers for all combinations of the existing decision options. Often, the overall score given is perceived as fictitious. In addition, the test people tend to concentrate too heavily on fully assigning the points.
Pairwise comparison	The problems associated with the simultaneous rating method can be avoided using the pairwise comparison as a part of an analytic hierarchy process, in which barriers are compared with one another qualitatively. A ranking scale is used, which simplifies the assessment so that only a comparative rating needs to be provided (e.g. "equivalent", "more significant"). The qualitative comparison leads to a quantitative rating. These quantitative ratings are entered into a rating matrix, in which all comparison pairs are allocated a quantitative rating.

Example matrix of a pairwise comparison of the significance of barriers

Number of barriers identified	Rating matrix							Standardised matrix V								Weighting vector W
zu: Compare	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	Row total	Weighting factor w1
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

Only the values in red have been filled out. In this case, four barriers were compared, where for example barrier B was rated as entirely more significant than barriers A and D and a great deal more significant than barrier C. After the conversion using the standardised matrix V, the weighting factors of the relative significance of the barriers are produced in the last column (in blue).

Source: Fichtner Consulting

Source: Adapted from GIZ (www.transparency-partnership.net/sites/default/files/klimawirkungen_engl_l3_3.pdf).

Further guidance on how to account for barriers on the expected RE addition of the policy for the assessment period is provided in in Section 7.5.4.

7.5.3 Step 3: Identify policies that may help overcome barriers

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.

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

Determine how the barriers effect the expected RE addition of the policy for 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%. 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. Technology 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 degree, the impacts of the barriers overlap, and account for this overlapping effect.
3. Account for the effect of all barriers on the expected RE addition of the policy for the assessment period. Calculate the potential impact of all barriers while accounting for the potential overlap. This outcome may be supported with an uncertainty range to express uncertainty about the likelihood and magnitude of one or more barriers (e.g. express the refined technical potential for the assessment period as a range of megawatts, as illustrated in Boxes 7.8 and 7.9).

Table 7.10 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 in Section 7.5.5, they can use country-specific studies that identify barriers and account for their effect, or use expert judgment to assist them in their assessment. Other tools are also available, such as the GIZ barriers-to-objectives weighting method,[38] 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.

7.5.5 Examples of accounting for other barriers

Boxes 7.8 and 7.9 provide examples of accounting for other barriers for an auction policy and feed-in tariff policy, respectively.

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[38] Available at: www.transparency-partnership.net/sites/default/files/klimawirkungen_engl_l3_3.pdf, Chapter 4.

TABLE **7.10**

Sample template for barrier analysis

Step 1		Step 2	Step 3	Step 4		
Barrier category	**Barrier description**	**Severity of barrier**	**Other policies addressing barrier**	**Impact factor**	**General level/ technology 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 to 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 technology-specific level.	Provide analysis on whether, and to what extent, the barrier overlaps with other existing barriers.

Source: Adapted from GIZ (www.transparency-partnership.net/sites/default/files/klimawirkungen_engl_l3_3.pdf).

BOX **7.8**

Auctions (example 1) – accounting for other barriers to refine expected renewable energy addition of the policy for the assessment period

1. **Estimate technical potential for the assessment period** (from Box 7.2) – **640 MW**

2. **Account for policy design characteristics** (from Box 7.4) – **550 MW**

3. **Account for effect on financial feasibility of RE technologies** (from Box 7.6) – **450 MW**

3. **Account for other barriers**

In **step 1**, the main barriers for the auction policy are identified using the list of barrier categories in Table 7.8:

- **Technical** – none
- **Regulatory and policy uncertainty** – none
- **Institutional and administrative** – none
- **Market** – high domestic fossil fuel subsidies
- **Financial or budgetary** – financing costs relatively high for power producers
- **Infrastructure** – grid infrastructure is not flexible enough to be linked to numerous RE installations
- **Lack of awareness of RE and skilled personnel** – none
- **Public acceptance and environmental** – none.

In **step 2**, the severity of each identified barrier is evaluated using expert judgment and ratings. None of the barriers are rated as very severe:

- High domestic fossil fuel subsidies – 1 (low).
- Financing costs relatively high for power producers – 2 (low to medium).
- Problems with flexibility of grid infrastructure – 3 (medium).

No other policies help overcome the barriers in **step 3**.

In **step 4**, the overall impact factor applied to the auctions is estimated using the barrier analysis. Identification of barrier-specific impact factors is based on expert judgment:

- **High domestic fossil fuel subsidies** – minus 2–5% (general level) based on experience with fossil fuel subsidies in the past.
- **Financing costs relatively high for power producers** – minus 5–10% (general level) based on market analysis of how available financing options for investors affect RE deployment and a survey with a representative sample of investors.
- **Problems with flexibility of grid infrastructure** – minus 10% (general level) based on analysis of current status of grid infrastructure and planned improvements over the course of the assessment period.

The identified barriers do not overlap. For this reason, the barrier-specific impacts can be aggregated, with the impact totalling between 17% and 25%, accounting for the uncertainty range for the overall impact of the identified barriers. As a result of the barrier analysis, the auctions will increase RE capacity by between **338 MW** and **374 MW**. The range represents the uncertainty for the specific impact of the identified barriers.

338–374 MW

BOX **7.9**

Feed-in tariff (example 2) – accounting for other barriers to refine expected renewable energy addition of the policy for the assessment period

1. **Estimate technical potential for the assessment period** (from Box 7.3) – **1,300 MW**

2. **Account for policy design characteristics** (from Box 7.5) – **800 MW**

3. **Account for effect on financial feasibility of RE technologies** (from Box 7.7) – **600 MW**

3. 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 7.8:

- **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 procedure is lengthy, non-transparent and cumbersome.
- **Market** – existing fossil fuel subsidies for low- and medium-income households.
- **Financial and budgetary** – concerns about financial solvency of only state-owned utilities with 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 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 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 fix the slow and non-transparent permit approval process addresses 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.

BOX **7.9,** continued

Feed-in tariff (example 2) – accounting for other barriers to refine expected renewable energy addition of the policy for the assessment period

1. Estimate technical potential for the assessment period (from Box 7.3) – **1,300 MW**

2. Account for policy design characteristics (from Box 7.5) – **800 MW**

3. Account for effect on financial feasibility of RE technologies (from Box 7.7) – **600 MW**

3. 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 judgment:

- **No technical standard and no domestic technology providers for rooftop solar PV panels** – 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 had estimated that 50 MW of the 800 MW technical potential for the assessment period of the policy directly links to rooftop installation, so this figure is 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 on how policy uncertainty affects investor behaviour using survey data with a small representative sample of investors.
- **Slow and non-transparent permit approval process** – barrier is overcome by other policy intervention to reform 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 behaviour in the past.
- **Concerns about financial solvency of only state-owned utilities with history of defaults** – minus 20–30% (general level), based on the assessment on how policy uncertainty affects investor behaviour using survey data with 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 personal 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 impact cannot be 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 between **262 MW** and **329 MW**. The range represents the uncertainty associated with the identified barriers.

262–329 MW

7.6 Summary of examples

The two examples illustrate how important it is to account for any factors that will affect the deployment of RE. Tables 7.11 and 7.12 summarize the results of examples 1 and 2, respectively, 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 the 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% of the technical potential. The feed-in tariff example, however, illustrates how policy design characteristics can have a disproportionate

TABLE **7.11**

Summarized results for example 1, Box 7.8 – auctions to increase renewable energy

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	338–374	–66 to –102	10–16

Abbreviation: -, not applicable

TABLE **7.12**

Summarized results for example 2, Box 7.9 – feed-in tariff to increase renewable energy

Step	RE addition (MW)	Adjustment	% reduction
Step 1: Estimate technical potential	1,300	-	-
Step 2: Account for policy design characteristics	880	–500	38
Step 3: Account for financial feasibility	600	–200	15
Step 4: Account for other barriers	262–329	–271 to –338	21–26

Abbreviation: -, not applicable

impact on deployment of RE. In that example, a full 38% of the technical potential was reduced by policy design characteristics. It is important to note that, in the latter example, other barriers also reduced the deployment of RE significantly.

Users should use caution when accounting for different factors, given the large impacts any of these can have on the final figure.

8 Estimating GHG impacts of the policy ex-ante

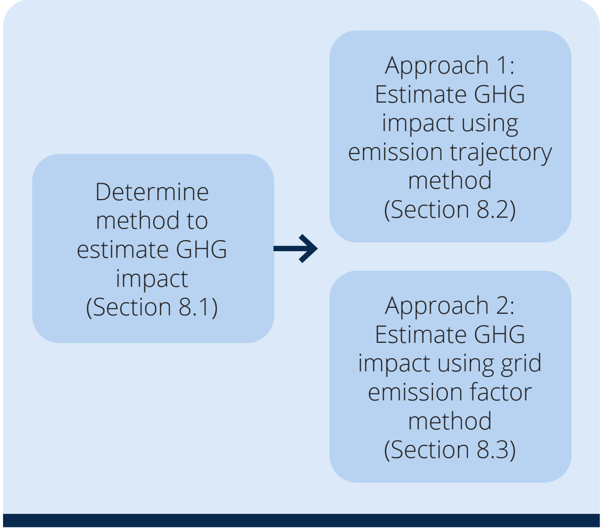
This chapter provides a method for the second step of ex-ante impact assessment: translating estimated RE addition in the policy scenario into GHG impacts. The GHG impacts can be expressed either as a GHG emissions level or as GHG emissions reductions achieved by the policy.

Checklist of key recommendations

- Choose the method for estimating GHG impacts based on the objectives of the assessment, and the policy's expected impact and time frame
- Estimate the emissions trajectory using energy models, where feasible, and otherwise using the method for limited data availability
- Estimate the GHG impact using a grid emission factor calculated using the CDM combined margin emission factor approach or emission factor modelling

FIGURE **8.1**

Overview of steps in the chapter



8.1 Determine method to estimate GHG impacts from renewable energy addition

Users should choose between two methods for translating estimated RE addition into GHG impacts: the emissions trajectory method and the grid emission factor method.

The emissions trajectory method develops a trajectory for future emissions from the electricity grid based on the expected future mix of generating technologies. The method involves making assumptions about the future electricity mix. It can be done using limited data or more complex models that model the energy sector development in detail. The resulting emissions trajectory can be used either as a stand-alone assessment to determine whether the trajectory is on track to meet a target, or in combination with a baseline scenario to determine the emissions reductions.

The grid emission factor 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. This method is appropriate for policies with a limited impact on the grid, since it uses simple assumptions about the future development of the entire energy sector. Users assume that the generated electricity resulting from the policy will displace carbon-intensive electricity generation and, to a certain extent, replace future carbon-intensive capacity additions. The grid emission factor reflects the emissions intensity of carbon-intensive electricity generation being displaced by the RE addition. For installations that feed into the electricity grid, this is equal to the grid emission factor, which serves as the baseline emission factor.[39]

Table 8.1 provides further information about the two methods.

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[39] A simple online tool to estimate avoided emissions based on average emissions in a specific country is available at https://irena.org/Statistics/View-Data-by-Topic/Climate-Change/Avoided-Emissions-Calculator.

TABLE **8.1**

Brief description of the simultaneous rating and pairwise comparison methods

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 • Emissions level calculations; not necessary to develop a baseline scenario	• Low level of standardization; many models are commonly used (e.g. LEAP), although there is no standardized approach for developing emissions trajectories
Grid emission factor	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; methodologies have been developed for a wide range of GHG emissions reduction interventions under the CDM, and revised and improved over time • 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

It is a *key recommendation* to choose the method for estimating GHG impacts based on the objectives of the assessment, and the policy's expected impact and time frame.

Users should choose between the emissions trajectory method and grid emission factor method considering the following issues.

8.1.1 Impact on the energy system

The policy may have a different degree of impact on the energy system and the energy mix in the sector. The degree of impact on the energy mix further depends on two factors: the size of the energy system and the size of the intervention.

The current share of variable renewable energy (VRE) generation in the energy system can give a rough indication of whether a system can accommodate additional VRE generation without needing major changes or experiencing major challenges. IEA[40] has classified energy systems in four phases according to the challenges the system faces when adding

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[40] IEA (2017a).

VRE (Figure 8.2). This classification is based on the share of VRE generation, the size of the system, transmission infrastructure, existing operation practices and existing levels of flexibility (e.g. hydropower facilities and interconnection to other systems) in the system. Energy systems in phases 1 and 2 can easily accommodate additional VRE generation, whereas systems in phases 3 or 4 would need to increase their flexibility to accommodate additional VRE generation. Although there is no clear number for the share of VRE generation in the system that defines a phase, the data roughly indicate that systems with a current share of VRE generation:

- of less than 5% correspond to phase 1
- of 5–10% correspond to phase 2
- of more than 10% correspond to phases 3 and 4.

Based on the correlation between current VRE generation share and the phase of the energy system, users can use the grid emission factor method or the emissions trajectory method to estimate GHG impacts from adding VRE to a system, as shown in Figure 8.2. In general, the emissions trajectory method can be used for a country with an energy system at any stage, but, because of its relative complexity and data intensity, this method is more appropriate for systems with larger shares of VRE. The grid emission factor method is more appropriate for energy systems that currently have a small share of VRE (i.e. less than 10%).

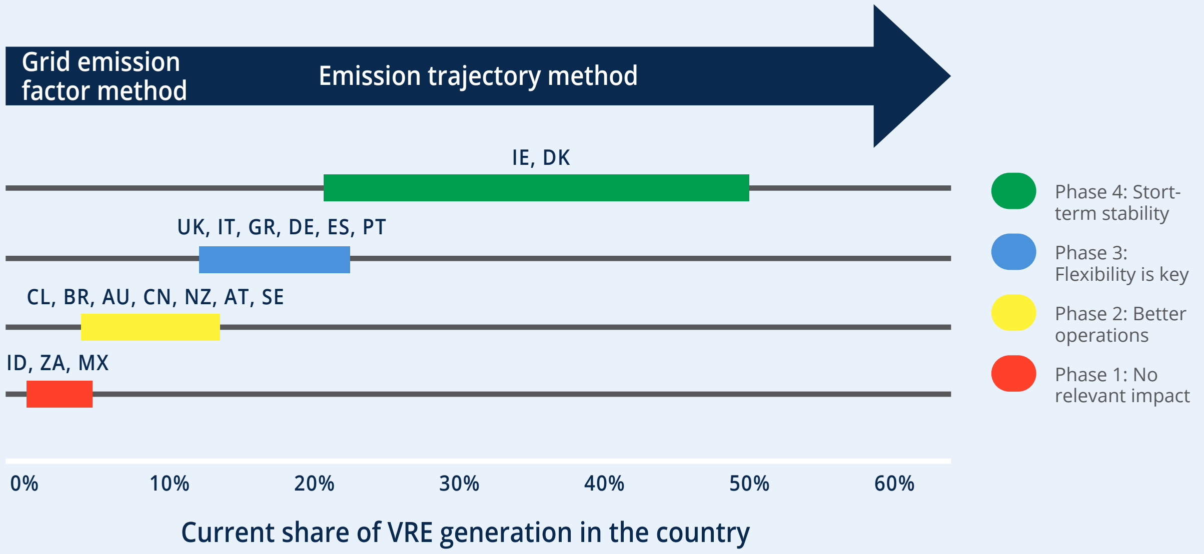
8.1.2 Time frame of the intervention

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

Users should also choose whether they want to estimate a GHG *emissions level*, or GHG *emissions*

FIGURE **8.2**

Guide to which assessment method is recommended, based on a country's current variable renewable energy share in the energy mix and the phase of its energy system



Abbreviations: AT, Austria; AU, Australia; BR, Brazil; CL, Chile; CN, China; DE, Germany; DK, Denmark; ES, Spain; GR, Greece; ID, Indonesia; IE, Ireland; IT, Italy; MX, Mexico; NZ, New Zealand; PT, Portugal; SE, Sweden; UK, United Kingdom; ZA, South Africa.

Source: IEA (2017a).

Note: Phases of the energy systems in this graph are indicative and based on IEA (2017a). Phases overlap in terms of VRE shares in the energy mix. The ranges and phase classification represent the status of a variety of countries in 2016.

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 (the grid emission factor method is not designed for these objectives).

- **GHG emissions reductions.** This is especially appropriate for assessing the effectiveness of policies, improving their design and implementation, and reporting on implementation progress – for example, in the context of achieving NDCs. Either the emissions trajectory method or the grid emission factor method can be used to meet these objectives.

Where the results of the assessment will be used in the GHG accounting of an NDC, users should consider aligning the base year for the assessment with the base year of the NDC and related targets. For this purpose, input parameters (e.g. activity data, emission factors, socioeconomic data) used to estimate baseline emissions of RE policies should be aligned with similar parameters used for setting NDC targets, and relevant GHG accounting and reporting under the Paris Agreement.

8.2 Approach 1: Estimate GHG impacts using emissions trajectory method

An emissions trajectory is used either on its own (to determine whether the GHG emissions trajectory is on track to meet an RE target) or in combination with a baseline scenario (to determine the GHG emissions reductions the policy is estimated to achieve). The steps below are followed for estimating emissions trajectories for both policy scenarios and baseline scenarios.

It is a *key recommendation* to estimate the emissions trajectory using energy models, where feasible, and otherwise using the method for limited data availability. If the user is determining GHG emissions reductions, the same approach should be used for both the baseline scenario and the policy scenario.

Where the results of the assessment will be used to meet the reporting requirements of the transparency framework, users should consider aligning the parameters used for the emissions projections of RE policies with those used to develop sectoral projections to meet relevant reporting requirements. This includes the time frame – that is, the starting and final years of the projections developed for RE policies should be the same as the starting and final years of the energy sector projections. Some parameters used for the projection of GHG impacts of RE policies can also be used as key indicators for projections developed to meet reporting requirements of the transparency framework.

8.2.1 Estimate emissions trajectory using an energy model

Several institutions have developed globally applicable models to support countries with analysing their energy policy and forecasting GHG emissions under different scenarios. Table 8.2 provides an overview of a few selected energy system analysis models. Users can use these and other suitable models to estimate the emissions trajectory. The RE addition calculated in Chapter 7 should be used as an input for these models, such that the resulting emissions trajectory is based on the additional RE deployment that the policy is expected to achieve.

The Climate Smart Planning Platform[41] provides an in-depth overview of a wide array of analytical models, tools, methods, procedures and guides for assessment of policy and investment implementation. This overview can inform users' choice.

8.2.2 Determine emissions trajectory using method for limited data availability

Where data availability is limited, users should follow the three steps set out below.

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[41] Available at: www.climatesmartplanning.org.

TABLE **8.2**

Overview of selected energy system analysis models

Criterion	TIMES	LEAP	EnergyPLAN	PROSPECTS+	GACMO
Developer	IEA – ETSAP	Stockholm Environment Institute	Sustainable Energy Planning Research Group at Aalborg University, Denmark	NewClimate Institute and Climate Action Tracker	UNEP DTU
Purpose of model	• Model of energy system • GHG emissions from energy system	• Model of energy system • GHG emissions from energy system	Model of energy system	• Model of energy system • GHG emissions from energy system	• Development of business-as-usual scenario • GHG emissions from energy system
Complexity	Complex	Medium–complex	Medium–complex	Simple–medium	Simple
Sectors covered	• **Energy supply:** all primary energy sectors, incl. heat • **Energy demand:** industry, commercial and tertiary, households, transportation	• **Energy supply** • **Energy demand:** household, industry, transport, commercial • Non-energy sector emissions can be added	• **Energy supply:** all primary energy sectors, incl. heat • **Energy demand:** industry, transport, cooling, desalination • **Storage and balancing**	• **Energy supply:** electricity and heat generation • **Energy demand:** transport, residential and commercial buildings, cement, steel, other industry, oil and gas production, agriculture, waste	• **Energy supply:** only fossil fuel • **Energy demand:** agriculture, energy efficiency, infrastructure and industry, transport
Cost calculations	Yes	Yes	Yes	No	Yes
Technology coverage	**Conventional:** oil (all), gas, coal (incl. lignite), nuclear **RE:** wind, solar, biomass, hydro. Single plant granularity	• **Conventional:** oil (all), gas, coal (incl. lignite), nuclear • **RE:** biomass (gasification, pyrolysis, digestion), waste, wind, hydro, solar (PV and CSP), geothermal, biofuel	• **Conventional:** nuclear, gas, oil, coal • **RE:** wind (onshore and offshore), solar (PV and CSP), wave, hydro, tidal, biomass, geothermal • **Storage**	• **Conventional:** nuclear, gas, oil, waste, coal • **RE:** hydro, geothermal, biomass, wind, solar, marine, waste, biofuel	• **Conventional:** oil (gasoline LPG, jet fuel, diesel, heavy fuel oil), coal (incl. lignite), gas, nuclear • **RE:** geothermal, hydro, wind, solar, biomass

TABLE 8.2, continued

Overview of selected energy system analysis models

Criterion	TIMES	LEAP	EnergyPLAN	PROSPECTS+	GACMO
Modelling environment	Excel-based input code in GAMS	Proprietary software; runs only on Windows	Freeware for Windows; code in Delphi Pascal	Excel	Excel
Free or at purchase	At purchase (fees vary)	At purchase (fees vary) Free (for government agencies in lower- and low-middle-income countries)	Free (on registration)	Free (available on request)	Free
URL	http://iea-etsap.org/index.php/etsap-tools/model-generators/times	http://sei-us.org/software/leap	www.energyplan.eu/getstarted	https://newclimate.org/2018/11/30/prospects-plus-tool/	www.cdmpipeline.org

Abbreviations: CSP, concentrated solar power; ETSAP, Energy Technology Systems Analysis Program; LPG, liquefied petroleum gas

Step 1: Project future electricity demand

The starting point for any energy supply emissions trajectory is to understand how electricity demand develops over time. Choose between the following approaches, or a combination of these approaches:

1. **Use existing country-specific electricity demand forecasts.** Potential data sources include the ministry of energy, national energy research institutes and international agencies, such as IEA. Where possible, use national data sources that are widely accepted among policymakers, and developed or endorsed by the government.

2. **Where country-specific data and resources are not available, data may be scaled down from regional scenarios.** The easiest approach is to apply growth rates of electricity demand from the regional scenarios to the historical data on electricity demand available for the country. However, consider how representative the regional development is of national development. For example, the IEA World Energy Outlook database includes Canada, the United States and Mexico in the North American region. Applying the growth rate for North America to historical data for Mexico would underestimate the growth in the energy sector, because Mexico's current levels of RE are much lower than those of the United States and Canada.

3. **Estimate the future electricity demand.** Where no electricity demand forecast for the country or region is available, simple assumptions can be made to estimate the electricity growth in the sector.

   a. Extrapolate historical growth rates. Extrapolate historical data on electricity demand using linear or other trends that align with historical development.

   b. Link electricity demand to population growth. Calculate current demand per capita and use population growth projections to estimate future total demand.

   c. Link electricity demand to growth in gross domestic product (GDP). This assumes that electricity growth and GDP growth are coupled. Bear in mind that certain processes have led to their decoupling, and make additional assumptions about autonomous energy efficiency improvements occurring in the economy.

Step 2: Project future electricity generation
The next step is to calculate the total required electricity production by accounting for transmission and distribution losses, as well as the power plants' own use of electricity:

Equation 8.1

$$\text{Total electricity generation}_i = \frac{\text{Total electricity demand}_i\ [\text{MWh}]}{1 - \text{TransmissionAndDistributionLoss}\ [\%] - \text{OwnUse}\ [\%]}$$

Historical transmission and distribution losses (percentage of gross electricity generation) for most countries are available free of charge from the World Development Indicators database.[42] Five-year averages of transmission and distribution losses per region, as well as minimum, maximum and median values from individual countries, are shown Table 8.3. If relevant, absolute transmission and distribution losses can be estimated by multiplying the share of transmission and distribution losses (percentage of output) by the future electricity output (in MWh).

TABLE **8.3**

Brief description of the simultaneous rating and pairwise comparison methods

Region	Transmission and distribution losses (% of output), average (2010–2014)
East Asia and Pacific	5.6
Europe and Central Asia	8.0
Middle East and North Africa	13.1
Sub-Saharan Africa	11.5
Latin America and Caribbean	15.0
Central Europe and the Baltics	7.7
Caribbean small states	9.4
OECD members	6.4
Least developed countries: United Nations classification	15.9
World	8.2
Minimum (Singapore)	2.3
Median	11.2
Maximum (Togo)	68.7

Source: World Development Indicators (https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS)
Abbreviation: OECD, Organisation for Economic Co-operation and Development
Note: Minimum, maximum and median values are calculated from the average between 2010 and 2014 for all available countries.

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[42] Available at: https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS.

The global average of own use of electricity by electricity producers is about 5% of total generation.[43] There is a large range across countries, depending on the composition of the power generation capacity of a country, as well as the vintage structure.

Step 3: Project future electricity mix

The next step is to develop projections on future electricity mix. First calculate electricity generation by technology, based on the current electricity mix. This information can be obtained from national sources (e.g. ministry of energy) and international sources.[44] To estimate the future electricity mix, choose between the following approaches, or a combination of these approaches:

1. **Assume that the share of different technologies in the electricity mix remains as is.** Use data on the shares of different technologies from the most recent year for which data are available and increase (or decrease if electricity demand is falling) all of them in proportion to their current mix. This can be the best assumption where the future energy mix development is unknown.

2. **Continue historical trends for the shares of different technologies in the electricity mix.** Carry past sectoral trends into the future. This approach can lead to unreasonable results for longer time frames where certain shares have experienced high growth rates in the past, but are unlikely to do so in the future. Apply individual adjustment to account for factors such as those listed in Table 8.4.

3. **Assume that certain technologies decrease more (or less) than others.** This approach is realistic under the following conditions.

    a. There is evidence that a certain technology will be more relevant in the future energy system than in an alternative system. For example, a national study may forecast the development of the future energy mix from trends such as the replacement of certain technologies by natural gas. A country’s climate strategy may be leading towards the decarbonization of the power sector. In such a case, the bridge technology (such as natural gas), may be preferred over coal.

    b. Changes in system characteristics are now favouring certain technologies over others. For example, as shares of intermittent RE sources such as wind and solar become increasingly significant, the energy mix shifts from being baseload focused towards a more flexible market regime, which may, in turn, favour certain technologies – such as natural gas – over others.

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[43] Authors’ calculations based on IEA (2018).

[44] International sources include IEA, “Data and statistics” (https://www.iea.org/statistics); the U.S. Energy Information Administration, “International energy statistics” (https://www.eia.gov/world/international/data/browser); and The Shift Project Data Portal. “Electricity by source” (http://www.theshiftdataportal.org/energy#Electricity).

TABLE **8.4**

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 have lead times of 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. **Middle 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 lifetimes. 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.	**Historical investment:** BNEF (2019) (private); Frankfurt School–UNEP Collaborating Centre and BNEF (2018); IEA (2018b); IRENA (2019c) **For technology lead times,** see Table 7.4 **For technology lifetimes,** see IEA and NEA (2015); Eurek et al. (2016)
Status of abundance of natural resources in the region/country	**Renewable resources** Renewable energies such as hydro, geothermal or wind are constrained to the places where that resource is abundant. If these resources have already been exploited significantly, it is unlikely that additional power plants from these technologies would be built in a country/region. By comparing a resource map and existing power plants, users can get a sense of the possible future addition of a certain kind of technology. **Conventional resources** Studies[a] 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 abundance of fossil fuel resources, its VRE addition is likely to lag behind.	National or international databases on natural resources (see Tables 7.1 and 7.2)
Historical and projected fuel prices	As a main component of the 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).	Lazard (2018); IRENA (2018b, 2019a); see also Appendix A
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.	IEA (2017b, 2018c)

TABLE **8.4,** continued

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

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 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 later used when demand increases. Hydro capacity can also be used as storage. **Transmission and distribution 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: IRENA (2019d) Factors that may affect changes in an energy system are presented in Table 7.10. Energy efficiency: Castro-Alvarez et al. (2018) General: World Bank (2018) NewClimate Institute, Germanwatch and Allianz SE (2018) Own analysis adapted from de Villafranca Casas et al. (2018)

[a] Pfeiffer and Mulder (2013); Papiez, Smiech and Frodyma (2018).

It is important to consider policy interactions within a country when developing the emissions trajectory. Where the policy is embedded in an integrated energy policy and/or other polices are in place that influence the generation mix, consider the effect these interactions have on the calculation of the remaining electricity generation.

After estimating the future electricity demand (step 1) and the future electricity mix (step 2), cross-check assumptions (including views on compound annual growth rates for electricity demand or future electricity mix development) through consultation with national sectoral experts.

Step 4: Calculate total CO_2 emissions from electricity generation

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 available in national studies or other sources. Unlike the emission factors described in Section 8.3, these do not change significantly in response to changes in the electricity mix, so results from existing sectoral modelling exercises can be used.

Calculate technology-specific emission factors using historical emissions (tCO_2/MWh), which are readily available from the IEA CO_2 Emissions from Fuel

Combustion database[45] or can be calculated from national statistics (see equation 8.2).

Equation 8.2

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

where

EF = the emission factor of an electricity generation technology in a certain year

TE_EG = the total emissions from electricity generation of a technology

EG = the electricity generation

i = the fossil fuel used for electricity generation (i.e. coal, lignite, gas, oil)

t = the year the electricity was generated.

Table 8.5 shows average emission factors of specific power plant types in different regions of the world.

Future specific emissions can be derived 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 that they improve over the years – that is, that there are energy efficiency improvements for the technology. However, this is only realistic where current plants will be retrofitted or where the construction of more-efficient plants is planned, so it is important to carefully consider how probable this is. For coal, based on the IEA World Energy Outlook 2018 scenarios, the average power plant efficiency improvement (and thus the

TABLE 8.5

Average emission factors (2012–2016) of specific power plant types in different regions

	Average emission factor ($MtCO_2/GWh$)							
Power plant technology	World	Africa	Americas	Asia	Europe	Oceania	OECD total	Non-OECD total
Anthracite-fired power plant	0.97	NA	0.93	0.96	1.00	NA	0.84	1.03
Other bituminous coal-fired power plant	0.91	1.04	0.91	0.91	0.89	0.88	0.88	0.93
Sub-bituminous coal-fired power plant	0.96	NA	0.95	0.99	1.09	0.87	0.94	1.00
Lignite-fired power plant	1.05	1.35	1.04	1.12	0.98	1.28	1.03	1.11
Natural gas–fired power plant	0.45	0.46	0.42	0.47	0.39	0.50	0.41	0.50
Crude oil–fired power plant	0.88	0.85	1.06	0.87	NA	NA	0.62	0.97

Sources: Based on IEA (2018a); IEA CO2 Emissions from Fuel Combustion database (www.oecd-ilibrary.org/energy/data/iea-co2-emissions-from-fuel-combustion-statistics_co2-data-en).

Abbreviations: NA, not available; GWh, gigawatt-hour; OECD, Organisation for Economic Co-operation and Development

Note: The regions correspond to the United Nations classification (https://population.un.org/wpp/DefinitionOfRegions).

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[45] Available at: www.oecd-ilibrary.org/energy/data/iea-co2-emissions-from-fuel-combustion-statistics_co2-data-en.

emissions intensity) of 1–10% over the period 2016–2030 can be expected, depending on the amount of new, more efficient coal power plants built. For gas, the improvement rates could be higher (5–10%) for the same time period, and even above 10% where power plants are retrofitted or replaced by better technology (e.g. single cycle to combined cycle). For oil, it is realistic to assume no change, as no significant advances in power plant technologies are expected in the future.

Users should then apply technology-specific emission factors (tCO_2/MWh) to each technology (% MWh) in the electricity generation mix to calculate the emissions trajectory. The emissions trajectory is expressed in units of tCO_2e emitted in a given year, stated for each of the years for which the trajectory is being developed.

8.2.3 Calculate GHG emissions reductions (if relevant)

Where the objective is to estimate the GHG emissions reductions of a policy, users should determine a baseline scenario and estimate the associated emissions trajectory. GHG emissions reductions achieved by the policy are the difference between the policy scenario emissions trajectory and the baseline scenario emissions trajectory. An example of how to estimate these when limited data are available is given in Box 8.1.

The baseline scenario emissions trajectory should be estimated by following the same steps used for estimating the policy scenario emissions trajectory (set out in Sections 8.2.1 and 8.2.2). The same approach used for the policy scenario (energy model versus method for limited data availability) should be used for the baseline scenario.

The following should be considered when determining the baseline scenario:

- Which policies should be included and what time frames do they have?
- Which non-policy drivers and/or sectoral trends should be included?
- How would the sector have developed without the policy? What assumptions should be made regarding technologies that would have been implemented in the absence of the policy?

The policies covered by this methodology and/or other policies can be included in the baseline scenario. The sources of data for developing assumptions on such policies may include government policies, regulations and plans; forecasting models; expert interviews; and market assessment studies for supply and demand projections.

Users should also develop assumptions on non-policy drivers and sectoral trends, including load forecasts, fuel prices, grid storage capacity, RE technology prices, population and GDP.

Users could consider developing multiple baselines rather than just one, each based on different assumptions. This approach produces a range of possible emissions reduction scenarios.

The last step is to calculate the GHG emissions reductions achieved by the policy. This is calculated by subtracting, for the given year, the emissions associated with the policy scenario from the emissions associated with the baseline scenario.

BOX **8.1**

Example of estimation of GHG reductions from renewable energy policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory (using proxies because of limited data availability)

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

61.7–82.3 $MtCO_2$/year

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,[44] the Enerdata "Global energy statistical yearbook",[45] World Bank population data[46] or United Nations population data[47]) 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.[48]

For a hypothetical country, electricity demand per capita in 2017 is calculated as follows:

$$EDpC_t\left[\frac{kWh}{capita}\right]=\frac{TED_t\left[\frac{kWh}{year}\right]}{Pop_t\left[\frac{capita}{year}\right]}$$

$$EDpC_{2017}=\frac{12 \times 10^{10}\ kWh/year_{2017}}{40 \times 10^{6}\ capita_{2017}}=\frac{3{,}000\ kWh}{capita}$$

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.

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[46] Available at: https://www.iea.org/statistics.

[47] Available at: https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html.

[48] Available at: https://data.worldbank.org/indicator/sp.pop.totl.

[49] Available at: https://population.un.org/wpp/DataQuery.

[50] Sources include World Bank (2019). Electric power consumption (kWh per capita) (https://data.worldbank.org/indicator/eg.use.elec.kh.pc); and the Climate Action Tracker (https://climateactiontracker.org/data-portal).

BOX **8.1,** continued

Example of estimation of GHG reductions from renewable energy policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory (using proxies because of limited data availability)

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)	-	2.5	2.2	1.7

Abbreviation: -, not applicable

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

$$GR_{t2} = \left[\left(\frac{EDpC_{t2}}{EDpC_{t2}}\right)^{\frac{1}{t2-t1}} - 1\right] \text{ x } 100$$

The compound annual growth rate between 2005 and 2010 is:

$$GR_{2005-2010} = \left[\left(\frac{2{,}600\left[\frac{kWh}{capita}\right]_{2010}}{2{,}300\left[\frac{kWh}{capita}\right]_{2005}}\right)^{\frac{1}{2010-2005}} - 1\right] \text{ x } 100 = 2.5\%$$

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

$$GR_{2005-2017} = \left[\left(\frac{3{,}000\left[\frac{kWh}{capita}\right]_{2017}}{2{,}300\left[\frac{kWh}{capita}\right]_{2005}}\right)^{\frac{1}{2017-2005}} - 1\right] \text{ x } 100 = 2.2\%$$

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[49] up to 2100. 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

$$TED^{min}_{2030} = 3{,}000\left[\frac{kWh}{capita}\right]_{2010} \text{ x } 45\text{x}10^6\ capita \text{ x } \frac{1GWh}{10^6 kWh} = 135{,}000GWh$$

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

$$EDpC_{2030} = EDpC_{2017} \text{ x } \left(1+GR_{2015-2017}\right)^{(2030-2017)} + 1$$

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

$$TED^{max}_{2030} = 4{,}002\left[\frac{kWh}{capita}\right]_{2010} \text{ x } 45\text{x}10^6\ capita \text{ x } \frac{1GWh}{10^6 kWh} = 180{,}074GWh$$

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[51] United Nations Department of Economic and Social Affairs, Population Division (2017).

BOX **8.1**, continued

Example of estimation of GHG reductions from renewable energy policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory (using proxies because of limited data availability)

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 8.2.2) and 5% of own use.

To estimate total electricity generation (*TEG*), we simply apply equation 8.1:

$$TEG_{2030}^{min} = \frac{TED_{2030}^{min}}{1 - T\&D_{loss}[\%] - OwnUse[\%]} = \frac{135{,}000GWh}{1 - 11.2\%} = 152{,}027GWh$$

$$TEG_{2030}^{max} = \frac{TED_{2030}^{max}}{1 - T\&D_{loss}[\%] - OwnUse[\%]} = \frac{180{,}074GWh}{1 - 11.2\%} = 202{,}786GWh$$

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.[50]

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

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 2030, we will consider the following factors (see Table 8.4):

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.

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[52] International sources include IEA, “Data and statistics” (https://www.iea.org/statistics); the U.S. Energy Information Administration, “International energy statistics” (https://www.eia.gov/world/international/data/browser); and The Shift Project Data Portal. “Electricity by source” (http://www.theshiftdataportal.org/energy#Electricity).

BOX **8.1**, continued

Example of estimation of GHG reductions from renewable energy policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory (using proxies because of limited data availability)

Therefore, we assume the following share for 2030:

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geothermal	Biomass
Share (%)	15	10	42	3	10	12	6	2	0

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	Bio-mass
Min (GWh/year)	22,804	15,203	63,851	4,561	15,203	18,243	9,122	3,041	0
Max (GWh/year)	22,849	15,232	63,976	4,570	15,232	18,279	9,139	3,046	0

With the breakdown of electricity generation by technology, we now estimate emissions for this baseline.

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 8.5:

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
EF (tCO_2/MWh)	0.96	0.88	0.41

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:

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 2030 are between 61.7 $MtCO_2$/year and 82.3 $MtCO_2$/year.

BOX **8.1**, continued

Example of estimation of GHG reductions from renewable energy policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory (using proxies because of limited data availability)

2. Estimate policy scenario emissions trajectory

61.4–81.8 $MtCO_2$/year

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 7.8). 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.[51]

We estimate the specific yield for solar PV in terms of the capacity factor as:

$$Specific\ yield_{solar\ PV} = annual\ capacity\ factor \times annual\ average\ operation$$

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

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

$$EGmin_{2030} = 237MW \times 1{,}584 \frac{MWh/year}{MW} = 375GWh/year$$

$$EGmax_{2030} = 314MW \times 1{,}584 \frac{MWh/year}{MW} = 497GWh/year$$

As explained in Section 8.2.2 (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 8.4). 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 neighbouring countries' electricity systems
- has implemented policies for energy demand reduction (e.g. energy efficiency)
- has hydro capacity that could partially be used for storage.

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

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[53] Users might refer to national databases on capacity factors or capacity factors of a relevant benchmark country (e.g. see the overview of annual capacity factors for different technologies provided by the U.S. Energy Information Administration at https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b).

BOX **8.1,** continued

Example of estimation of GHG reductions from renewable energy policy as the difference between policy scenario emissions trajectory and baseline scenario emissions trajectory (using proxies because of limited data availability)

Thus, the final generation per technology in 2030 is:

Technology	Coal	Oil	Gas	Nuclear	Hydro	Solar PV	Wind	Geo-thermal	Bio-mass
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

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	13.4	26.4	**61.3**
Max ($MtCO_2$/year)	28.7	17.8	35.3	**81.8**

Thus, the emissions levels from the policy scenario emissions trajectory are 61.4–81.8 $MtCO_2$/year.

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

0.4–0.5 $MtCO_2$/year in 2030

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:

$$EmRed_{2030}^{min} = 61.7\frac{MtCO_2}{year} - 61.3\frac{MtCO_2}{year} = 0.4\frac{MtCO_2}{year}$$

$$EmRed_{2030}^{max} = 82.3\frac{MtCO_2}{year} - 81.8\frac{MtCO_2}{year} = 0.5\frac{MtCO_2}{year}$$

8.3 Approach 2: Estimate GHG impacts using grid emission factor method

The grid emission factor method uses simple assumptions about the development of the electricity sector and can be useful for policies with a limited impact on the grid. Many RE technologies do not result in any direct emissions; their grid emission factor is zero.[54] For others, such as biomass and large-scale hydro, there are associated emissions that need to be accounted for.

It is assumed that the generated RE electricity resulting from the RE policy will displace carbon-intensive electricity generation and, to a certain extent, replace future carbon-intensive capacity additions. The grid emission factor reflects the emissions intensity of the carbon-intensive electricity generation being displaced by the RE addition (expressed in tCO_2e/MWh).

It is a *key recommendation* to estimate the GHG impact using a grid emission factor calculated using the CDM combined margin approach or emission factor modelling. The two approaches for calculating the grid emission factor are discussed in Section 8.3.1. The GHG impact of the policy is then calculated by multiplying the grid emission factor with the estimated RE addition (Section 8.3.2).

8.3.1 Calculate grid emission factor

CDM combined margin approach

Grid emission factors have been used to assess the emissions impacts of projects under the CDM, and for bilaterally and multilaterally funded mitigation projects. The combined margin emission factor looks at the emissions impact of an addition of RE capacity to an electricity grid on the operation of existing plants (the operating margin) and future capacity additions (the build margin). A range of guidance and tools are available to help users calculate the emission factors of their grids. Table 8.6 provides an overview of key relevant resources.

The CDM Tool to Calculate the Emission Factor for an Electricity System listed in Table 8.6 outlines a method to calculate a combined margin emission factor. The combined margin is a blended emissions factor that is based on emission factors of existing power plants (operating margin) and on future capacity additions (build margin). Appendix D provides information about using the CDM Tool to Calculate the Emission Factor for an Electricity System, along with related guidance and resources for country-specific emission factors.

Emission factor modelling

Emission factor modelling can be used to capture changes in the electricity grid's structure over time and the impact of policies on the load characteristics of the grid.

Emission factor models use historical performance data from power plants. Emission factors are calculated by developing statistical models for variables that affect the emissions intensity of the grid. These variables include electricity export and import, trading and, to a limited extent, changes in power supply and demand. The United States Environmental Protection Agency AVERT (Avoided Emissions and Generation Tool) is an example of such a statistical model.[55] AVERT uses hourly and unit-level historical generation data, and models avoided emissions through implementation of energy efficiency or RE.

Emission factor models are useful because they reflect variations in load and frequent changes in emissions (e.g. hourly differences) based on power plants supplying to the grid. They are especially beneficial for countries with significant power imports, because they accurately capture the emissions intensity of the grid. In spite of these advantages, data used in these statistical models reflect historical emissions performance and do not adequately capture future changes in grid composition, infrastructure, policies and pricing. Where users intend to capture these trends, projection-based energy modelling approaches, discussed in Section 8.2.1, may be more useful.

8.3.2 Calculate GHG emissions reductions

The GHG emissions reductions achieved by the policy are calculated by multiplying the grid emission factor with estimated RE addition (estimated in Chapter 7). This is the GHG impact of the policy.

Where the policy involves hydro or biomass power plants, additional emissions may have to be subtracted to take account of CH_4 emissions

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[54] The lifetime GHG emissions caused by the construction and operation of RE installations can reasonably be excluded, as they are roughly equivalent to emissions that would be caused by the construction and operation of fossil fuel power plants.

[55] Available at: https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert.

TABLE **8.6**

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

Resources	Description	Source
CDM Tool to Calculate the Emission Factor for an Electricity System	• Detailed guidance providing calculation methodology • Country users use country-level data to calculate grid emission factors • Developed by UNFCCC secretariat	https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v2.pdf/history_view
IGES List of Grid Emission Factors	• Database of country-specific grid emission factors • Collated from information provided in project design documents • Developed by IGES and regularly updated	https://pub.iges.or.jp/pub/list-grid-emission-factor
IGES CDM Grid Emission Factor Calculation Sheet	• Excel-based calculation sheet based on the CDM tool • Uses country-level emission factor data collated from project design documents • Developed by IGES	https://pub.iges.or.jp/pub/iges-cdm-grid-emission-factor-calculation
IFI Approach to GHG Accounting for Renewable Energy Projects	• Guidelines for renewable energy projects	www.nib.int/filebank/a/1449216433/c78bcf00c64ba92b3a73673a2217be4d/5023-Joint_GHG_RE.pdf

Abbreviations: IFI, International Financial Institution; IGES, Institute for Global Environmental Strategies; UNFCC, United Nations Framework Convention on Climate Change

associated with reservoirs and emissions associated with growing energy crops, respectively. CDM methodologies provide guidance on estimating such emissions.

8.3.3 Example of calculating GHG impacts using grid emission factor method

BOX **8.2**

Example of calculating GHG impacts for a tender policy

The country generates 500,000 GWh/year of electricity. Its generation mix comprises 50% coal (250,000 GWh/year), 40% gas (200,000 GWh/year) and 10% 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 2017, 100 MW in 2018 and 500 MW in 2019 (total 640 MW).

The tender policy is expected to contribute to a national target of 1,000 MW of RE capacity by 2025.

The technical potential for the assessment period of the tender policy (640 MW) is reduced by 14% after the assessment of its design characteristics. Thus, the tender policy is expected to lead to 550 MW of RE deployment by 2025. 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%. Thus, the RE addition of the tender policy is estimated to be 338–374 MW (42–47% lower than the technical potential for the assessment period).

This estimate translates to a generation potential of 3,875–4,336 GWh of power between 2017 and 2025, assuming 24 hours per day and 330 days of annual operation with a 25% 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 grid emission factor approach.

The Ministry of Energy consults with regulatory commissions and utilities to define the spatial boundary of the grid. It decides to include both utilities and independent power producers in the spatial boundary of the grid. Power imports and exports are also included in the assessment. The operating margin and build margin of the grid are calculated. Using a simple operating margin and build margin, and typical weightings used under the CDM for solar and wind ($w_{OM} : w_{BM}$ = 0.75:0.25), the combined margin emission factor (*EF*) is calculated using the equation

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

$$EF_{grid,CM,y} = 0.82 \ tCO_2 e/MWh$$

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

$$\sum EG_y = 3{,}875 \ GWh \ to \ 4{,}336 \ GWh$$

The estimated GHG emissions reduction (*EmRed*) of the RE tender policy between 2017 and 2025 is

$$EmRed = \left[EF_{grid,CM,y} \times \sum EG_y\right] = 3{,}177{,}297 \ tCO_2e \text{ to } 3{,}555{,}546 \ tCO_2e$$

$$= 3.18 \ MtCO_2e \text{ to } 3.56 \ MtCO_2e$$