IRENA
International Renewable Energy Agency

IRENA FLEXTOOL

SUMMARY OF METHODOLOGY

January 2019

Flexibility is the capability of a power system to cope with the variability and uncertainty that solar and wind energy introduce at different time scales, from the very short to the long term, avoiding curtailment of power from these variable renewable energy (VRE) sources and reliably supplying all customer energy demand.

This brochure provides a summary of Power system flexibility for the energy transition, *Part 2: IRENA FlexTool methodology*, ISBN 978-92-9260-090-7.

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1. IRENA FLEXTOOL

1.1 INTRODUCTION

IRENA's assessment of flexibility is carried out with the IRENA FlexTool. The FlexTool is a **detailed but user-friendly tool** that intends to analyse not only the traditional concept of flexibility (concerning, for example, flexible thermal and hydropower generation with high ramping capability and very low start-up time), but also other innovative technologies that enrich the concept of flexibility, such as flexible demand, energy storage and sector coupling.

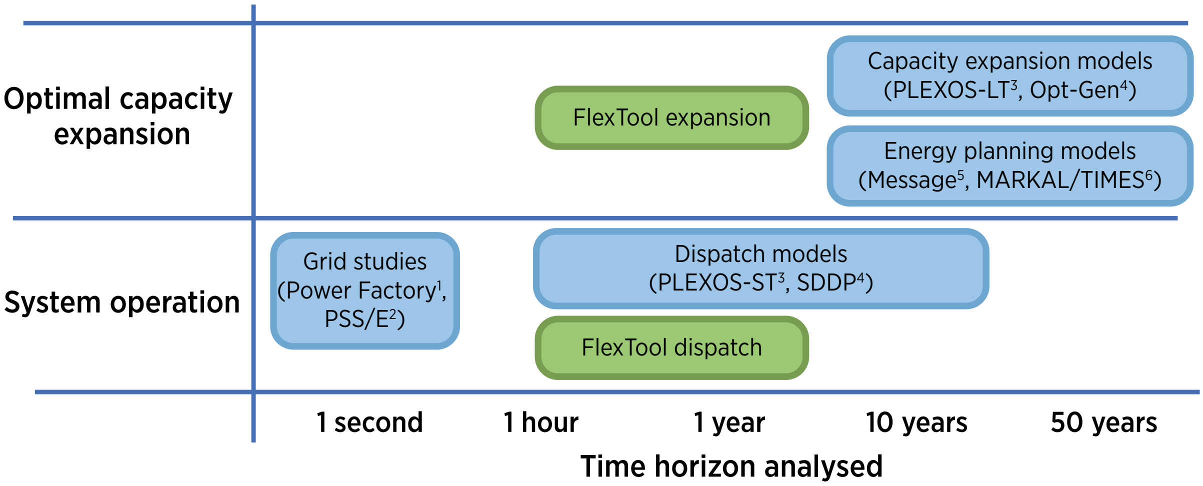
The FlexTool is capable, on the one hand, of **analysing system operations** using a time step that represents real-world challenges (an hour or less in the case of variable renewable energy, VRE) and, on the other hand, of carrying out **least-cost optimisation of the generation mix**, as well as flexibility solutions with regard to **grids, storage, the demand side and sector coupling**. The FlexTool, however, does not study the very short term (second/sub-second time scale); although this also is relevant for power system flexibility, it calls for another type of assessment.

The FlexTool is data-driven. This means that the model structure is relatively general, and the input data have a large role in specifying what the model does. To perform a **FlexTool simulation** the required inputs are, in brief: **demand, generation mix, hydrological data, VRE time series, interconnections and fuel costs**. If the system being analysed is divided into different nodes, transmission data – divided by node – are required in addition to the mentioned data.

The FlexTool was developed with the VTT Technical Research Centre of Finland Ltd., with the aim of assisting IRENA members in making a relatively quick assessment of potential flexibility gaps as well as highlighting the most cost-effective mix of solutions to fill in such gaps. It is currently the only **publicly and freely available (open-source) tool** that performs both **capacity expansion and dispatch** with a focus on power system flexibility.

The FlexTool looks at a one-year horizon and analyses system operations and capacity expansion with a focus on power system flexibility. Figure 1 shows where the FlexTool fits into the planning process in comparison with other existing modelling tools.

Figure 1. The IRENA FlexTool in the planning process



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1.2 TOOL SIMPLIFICATIONS AND ASSUMPTIONS

The relatively simple structure of the FlexTool provides many benefits but also has some limitations. Simplifications made in the tool include:

- Linear programming, which implies simplifications in the way start-ups and minimum stable load are considered.
- A deterministic model that has perfect foresight and that therefore does not consider forecast errors in a stochastic manner. That said, upwards operational reserve requirements are included in the model.
- A simplified representation of the internal transmission network (using a transport problem)[1] with a reduced set of nodes/areas.
- Power plant aggregation by type characterised with the most relevant technical parameters. Individual units also can be modelled, but aggregation is recommended to reduce computational time.
- Maintenance and outages are not considered.
- In the expansion mode, representative weeks are considered in the simulation. Selection of the representative weeks affects results and requires expert judgement or heuristic tools.
- The tool does not study issues related to the very short term (seconds/sub-seconds scale), such as stability, and does not consider voltage.

1 *The transport problem is a common optimisation issue in operations research. It involves obtaining the least-cost plan to distribute goods or supplies from multiple origins to multiple destinations. In this case the goods to distribute are megawatts of electricity.*

1.3 TOOL INPUT DATA REQUIREMENTS

Table 1. Input data requirements to run the IRENA FlexTool

System data (annual, each node)
Demand, imports, losses and capacity margin
Electricity transmission (each node)
Transmission and interconnection capacities
Data of generation capacity (each node)
Installed capacity, technical data of generators, hydro reservoirs capacity
Time-series data (8 760 hourly values, each node)
Electricity demand, hydro inflows, wind and solar photovoltaic (PV) generation, demand from other sectors (e.g., heat)
Fuel data
Fuel price and emission rate

1.4 MODEL OUTPUTS

Table 2. Outputs of the IRENA FlexTool

Flexibility indicators	
Loss of load (terawatt-hours (TWh) and %)	VRE curtailment (TWh and %)
Reserves shortage (megawatts (MW))	Capacity inadequacy (MW)
Spillage (TWh)	
Dispatch per generator and per node	
Transmission between nodes (and utilisation factor of lines)	
Costs	
OPEX	**CAPEX**
Fuel costs	Generation investments
Cost of carbon dioxide emissions	Transmission investments
Operation and maintenance costs	Storage investments
Cost of loss of load	Sector coupling investments (e.g., heat pumps)
Cost of curtailment	
Electricity price per node (marginal price)	
Ramping information (one-hour and four-hour ramps)	
Investments (invested transmission, generation, storage or sector coupling capacity)	
Other (e.g., dispatch and costs from other energy sectors)	

1.5 METHODOLOGY TO CONDUCT FLEXIBILITY STUDIES

The IRENA FlexTool reports a set of flexibility indicators and grid issues in the result file that helps to identify flexibility issues. It includes the following categories:

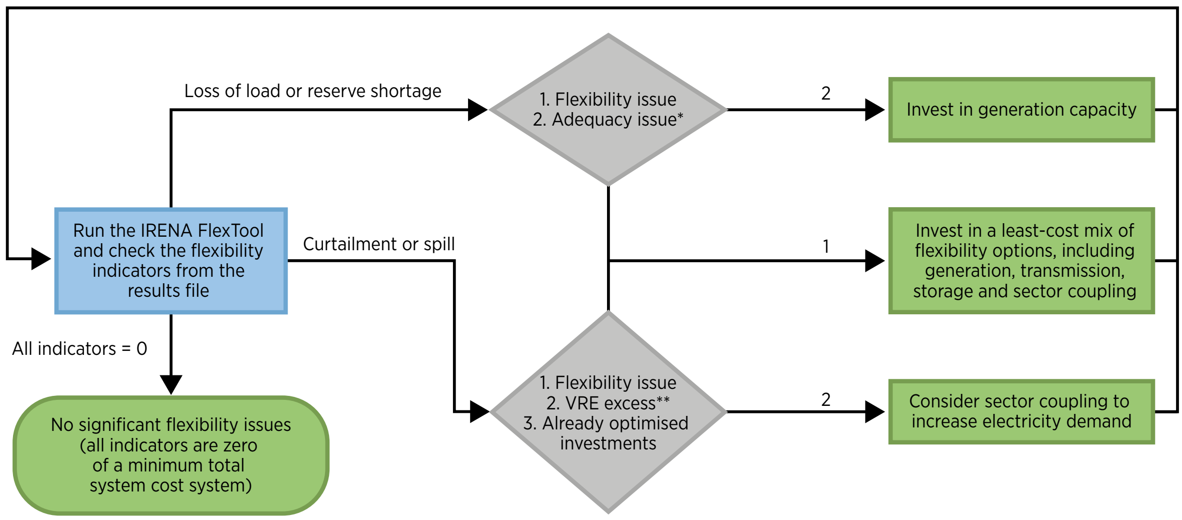
- **Loss of load (MW).** Occurs when the supply cannot match the demand and energy must go unserved. The tool shows the maximum amount of loss of load given in a single period.
- **Reserve shortage (max MW).** Occurs when the reserve requirement cannot be met. The tool shows the maximum amount of reserve inadequacy given in a single period.
- **Curtailment (max MW and annual TWh).** Occurs when VRE output has to be reduced because of inflexibility of the system or because VRE generation exceeds the demand. The tool shows the maximum amount of curtailment given in a single period and the total amount curtailed in a year.
- **Spillage (TWh).** Occurs when the water inflow exceeds the amount that can be used by hydropower generators when reservoirs are full. The tool shows the total amount of energy spilled in a year.

All of these are allowed in the model solution, but they add penalty costs as defined by the input data. The FlexTool tries to avoid the additional costs, but sometimes the system does not have enough capacity or flexibility, and some of these appear in the cost-optimal solution.

Reserve shortage and loss of load usually have high penalties and are severe issues in the solution, and the user should always check whether results are realistic. For instance if the loss of load penalty is extremely high, the operation costs might be too high with a very small amount of loss of load, or, in case the investment mode is run, the model might invest in expensive and unnecessary generation capacity just to avoid a small amount of loss of load. Curtailments and spills are associated with lower penalties. The user should assess whether those results are reasonable.

Figure 2 provides a brief overview on to how to check and solve flexibility issues in the IRENA FlexTool.

Figure 2. How to check and resolve flexibility issues: A quick guide to the IRENA FlexTool

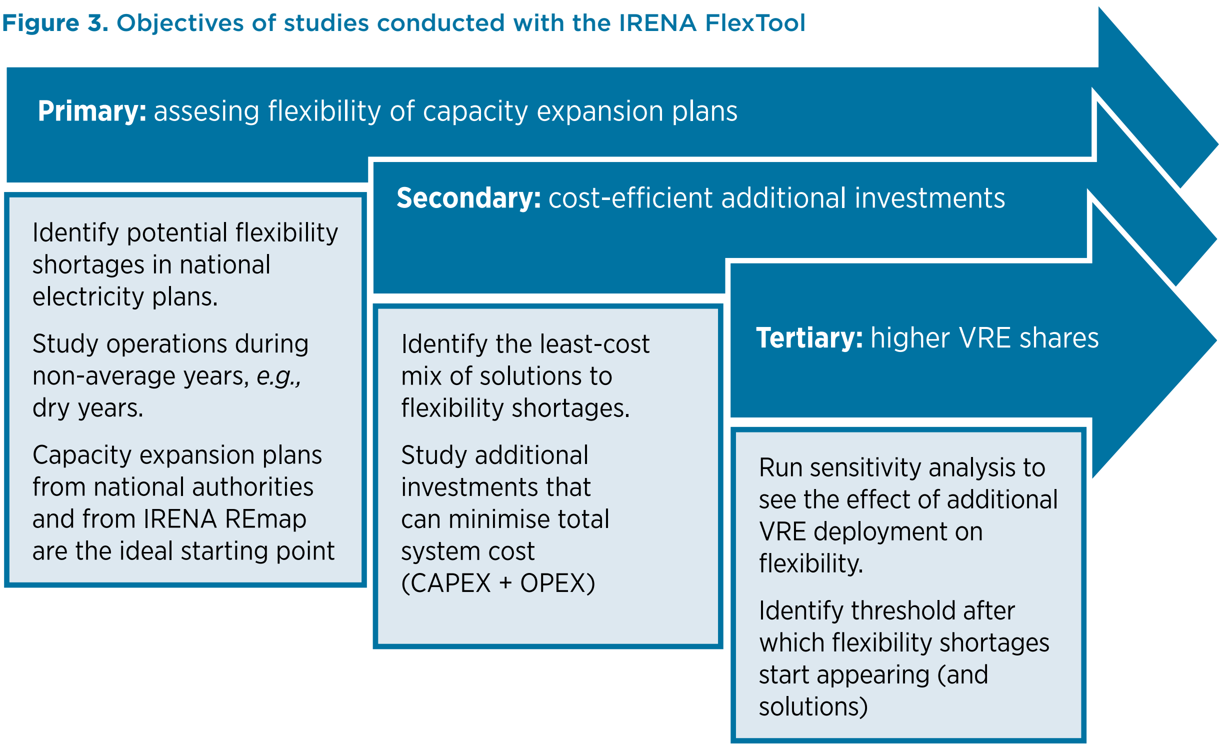


* An adequacy issue implies that annual generation is lower than annual demand and there is no transmission conggestion.

** VRE excess generation means that in some periods the total VRE generation is higher than demand.

1.6 FLEXIBILITY STUDY OBJECTIVES

Figure 3. Objectives of studies conducted with the IRENA FlexTool



1.7 STAKEHOLDERS AND ENGAGEMENT

The FlexTool application to a country typically starts with a self-assessment that shows a potential gap in the planning process, or simply an interest in comparing the approach currently applied with the new approach and tool from IRENA. The involvement of the right set of stakeholders is key to make the study possible and to ensure relevance, credibility and impact. Key stakeholders include the IRENA focal point (to identify agencies or ministries that can provide the data and discuss results) and relevant decision makers (to comment on and use the results), for example utility companies, transmission system operators and ministries.

After this IRENA sends an invitation letter to the country to initiate the flexibility assessment and starts collaborating with the relevant focal point for data collection and analysis, which might or might not be the same as the one participating in the engagement process.

Table 3 shows the main stakeholders that participated in the flexibility assessment in the four case studies developed.

Table 3. Key stakeholders for data collection in the flexibility assessment

<table>
<tr><th></th><th>Colombia</th><th>Panama</th><th>Uruguay</th><th>Thailand</th></tr>
<tr><td>Engagement</td><td rowspan="2">UPME (National Mining and Energy Planning Unit)</td><td rowspan="2">Electricity Transmission Company (ETESA) – transmission system operator of Panama

National Energy Secretariat (SNE)

National Dispatch Centre (CND)</td><td rowspan="2">Ministry of Industry, Energy and Mines (MIEM)</td><td>Department of Alternative Energy Development and Efficiency (DEDE) of the Ministry of Energy</td></tr>
<tr><td>Data collection</td><td>DEDE and Electricity Generating Authority of Thailand (EGAT), Energy Regulatory Comission (ERC) and Royal Irrigation Deparment.</td></tr>
<tr><td>Publication</td><td>(IRENA, 2018a)</td><td>(IRENA, 2018b)</td><td>(IRENA, 2018c)</td><td>(forthcoming)</td></tr>
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1.8 IMPACT SEEN IN THREE INITIAL CASE STUDIES

Colombia:
"Based on the results of the IRENA FlexTool analysis, UPME plans to add a chapter on power system flexibility to the next national power expansion plan, looking at the period 2018-2022." (IRENA, 2018a)

Panama:
"Adding this tool into the planning process could help the country design effective energy policies, particularly to develop a flexible power sector that is compatible with the decarbonisation needs implied by the Paris Agreement." (IRENA, 2018b)

Uruguay:

"MIEM recognises the IRENA FlexTool as a useful complement to these tools, providing an added set of flexibility indicators and allowing integrated assessments of sector coupling. The FlexTool, therefore reveals more options to boost flexibility." (IRENA, 2018c)

1.9 INDICATORS USED IN THE FLEXIBILITY STUDIES

A set of flexibility indicators was used in the case studies to measure 1) flexibility in the power system based on country information on current system and planned system for the future, 2) flexibility in a power system as an outcome of the simulations and 3) remaining flexibility in the power system. The first set of indicators is calculated based on the input data collection for the present and future years of the country or region to be studied, while the other two sets of indicators are calculated based on the results from the IRENA FlexTool simulations.

FLEXIBILITY ENABLERS BASED ON A COUNTRY'S POWER SYSTEM INFORMATION

Table 4. Flexibility enablers of a specific power system

Enabler	Units	Description
Interconnection capacity vs. average demand	–	Shows the ratio between interconnection capacity with neighbouring countries and the average electricity demand.
Generator ramping capabilities	MW/min	Represents the total ramping capability of the system's dispatchable generation (i.e., non-VRE generation), assuming that all units are online.
Matching of demand with VRE generation	%	Shows the correlation between the demand time series and the VRE time series.
Hydro inflow stability	%	Shows the standard deviation and variability of the historical hydro inflows.
Strength of internal grid	–	Expresses how strong the internal grid is and whether there is enough transmission capacity in the system.
Storage vs. annual demand	%	Shows how much storage capacity is available (including hydro reservoirs) in comparison to the total annual demand.
Geographical dispersion of VRE generation and demand	–	Shows how well VRE generation and demand are geographically matched (at node level).
VRE vs. minimum demand	–	Represents the likelihood of VRE overgeneration by comparing VRE installed capacity to minimum demand. The higher the ratio, the more likely – in absence of storage – VRE curtailment is to occur. This indicator should be assessed jointly with the storage indicator.

FLEXTOOL FLEXIBILITY INDICATORS

Table 5. Flexibility indicators assessed by the IRENA FlexTool

Indicator	Units	Description
Curtailment	Gigawatt-hours (GWh) and MW	Occurs when VRE output has to be reduced because of the inflexibility of the system or because VRE generation exceeds the demand.
Loss of load	GWh and MW	Occurs when supply cannot match demand, and part of the electricity demand must go unserved (e.g., so-called load shedding).
Spillage	GWh and MW	Occurs when water inflow exceeds the amount that can be used by hydropower generators and reservoirs are already full.
Reserve inadequacy*	GWh and MW	Occurs when the reserve requirement cannot be met.

* Note that the model only considers reserves as capacity (MW), which will then not be available to generate. Reserves in the FlexTool are never activated, and therefore for the reserve inadequacy indicator the units are not energy (GWh), but power multiplied by hours.

INDICATORS TO MEASURE THE REMAINING FLEXIBILITY IN THE SYSTEM

Indicator	Units	Description
Residual ramping capability	MW/min	Measures how much ramping capability from dispatchable generation (i.e., non-VRE generation) is available for the system for the following time period (typically one hour). The indicator refers to upward ramping capability since downward ramping is not an issue, as it can be provided almost instantaneously by utility-scale VRE, in cases where thermal generators might be too slow or already at their minimum stable operating point.
Share of time when the transmission is not congested	%	Measures the average transmission capacity available in the system and shows the most congested transmission corridors between areas. Since the FlexTool representation of transmission is not analysing the alternating current (AC) power flow this value is a direct current (DC) approximation. This only applies to models with more than one node.
Remaining interconnection capacity	%	Measures how much interconnection capacity is available in the system on average. The indicator also can capture the presence (or absence) of active cross-border trading.
Unused hydro reservoir capacity	%	Measures how much available storage capacity remains unused in the hydro reservoirs, i.e., how far the reservoirs are from spilling water (for example, if the unused reservoir capacity is 0%, then the reservoirs are full, and water might be spilt).

Note: All indicators are estimated for the annual average of all time periods (typically of one hour) and for the most critical time period (or time interval), which represents the worst conditions for each of the indicators under a modelled scenario (e.g., the hour with the lowest ramping capability).

1.10 EXAMPLES OF APPLICATION

To show how the tool can be useful to identify flexibility issues and propose solutions, a set of representative examples is shown:

EXAMPLE A

Issue:

The system being analysed has four nodes and three power lines. In the western node demand is concentrated, while in the southern node there is excess VRE penetration. The power line connecting the south and west is, however, very weak and results in loss of load in the western node and in VRE curtailment in the southern node.

Solution:

Under this scenario the system can consider investing in additional transmission capacity between the south and west or investing in VRE with storage in some of the system nodes. This analysis is solved with the investment phase of the FlexTool.

Figure 4. Simplified diagram of the power system analysed and flexibility indicators

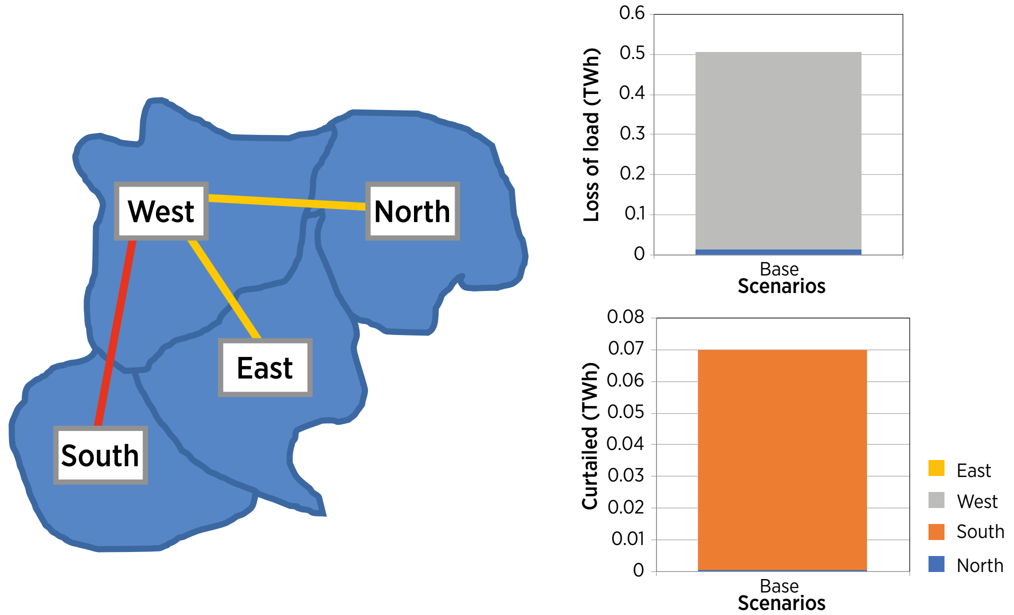
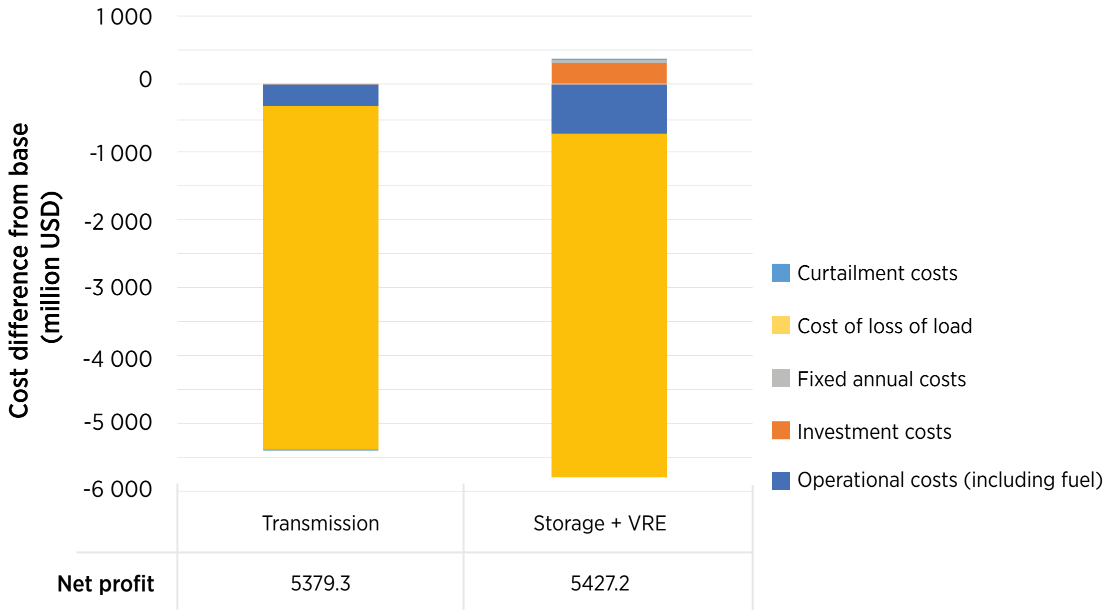


Figure 5. Cost comparison of investing in transmission and investing in VRE with storage



EXAMPLE B

Issue:

The system being analysed has a very high solar PV penetration, creating what is known as the duck curve. The rest of the generation mix is composed of low-ramping thermal generation with an upward ramping capability of 102 MW per hour. The large ramping requirement that solar PV introduces into the system turns into loss of load and VRE curtailment since the thermal mix does not have enough ramping capabilities. Curtailment is produced when solar PV is ramping down to avoid loss of load as much as possible.

Solution:

The system needs additional ramping capability. The most common solution has been installing flexible thermal generation (e.g., open-cycle gas turbine, or combined-cycle gas turbine), but the FlexTool can consider storage or sector coupling. The figure shows an example with batteries.

Figure 6. Curtailment and loss of load as a result of the low ramping capability of thermal units

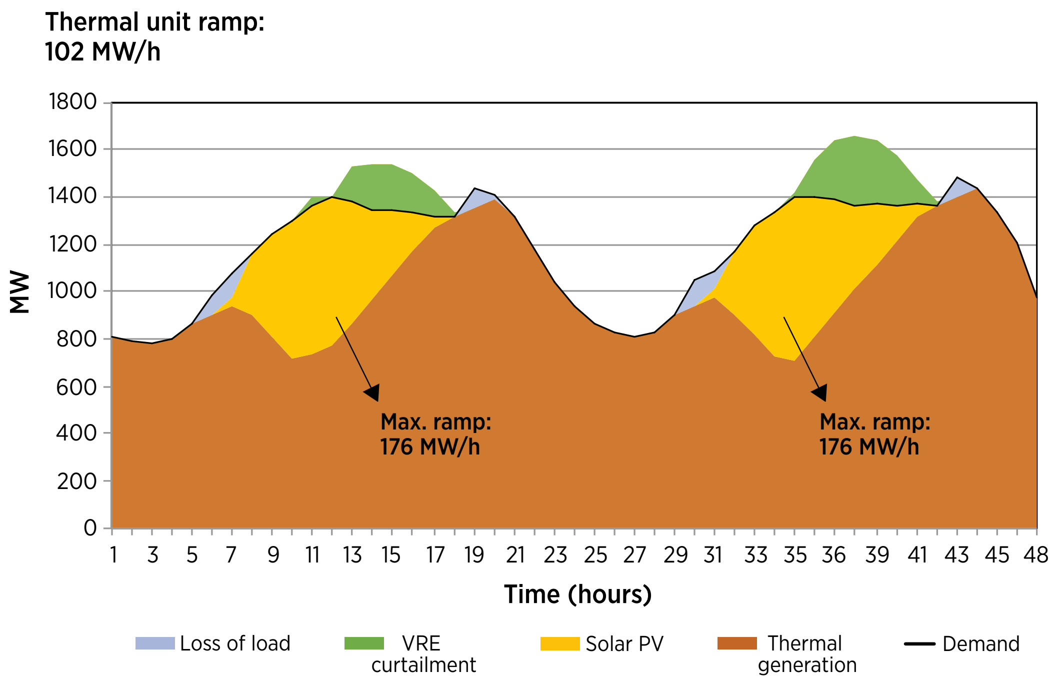
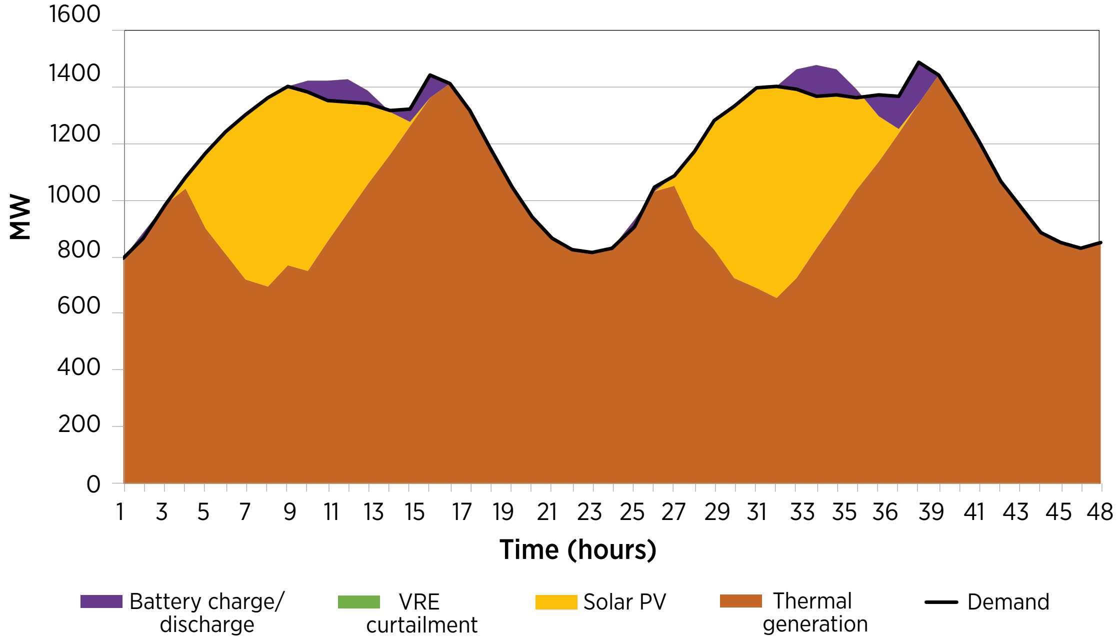


Figure 7. Storage as a solution to some of the flexibility issues, providing high ramping capabilities



FURTHER READING

IRENA (2018a), *Colombia power system flexibility assessment: IRENA FlexTool case study.* International Renewable Energy Agency, Abu Dhabi.

IRENA (2018b), *Panama power system flexibility assessment: IRENA FlexTool case study.* International Renewable Energy Agency, Abu Dhabi.

IRENA (2018c), *Uruguay power system flexibility assessment: IRENA FlexTool case study.* International Renewable Energy Agency, Abu Dhabi.

IRENA (2018d), *Power system flexibility for the energy transition. Part 1: Overview for policy* makers, International Renewable Energy Agency, Abu Dhabi.

IRENA (2018e), *Power system flexibility for the energy transition. Part 2: IRENA FlexTool methodology,* International Renewable Energy Agency, Abu Dhabi.

IRENA (forthcoming), *Thailand power system flexibility assessment: IRENA FlexTool case study.* International Renewable Energy Agency, Abu Dhabi.

Download the IRENA FlexTool:

irena.org/publications/2018/Nov/Power-system-flexibility-for-the-energy-transition

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