Overcoming challenges in large scale deployment of renewables
- Part I: Intermittency -

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The Energy Transition

The ongoing Energy Transition can be described as a transition from an Oil-based economy to a Green Electron-based economy, with the objective to become net-zero CO2 emissions within the next 30 years. The structure of the world primary demand is changing, and while the O&G demand will fall, the electricity demand will increase as we are trying to decarbonize our systems.

In the past 10 years, renewable energy technologies as electricity generation systems have emerged as the mean with the highest potential to help us to achieve this goal. They are becoming the backbone of our energy systems worldwide.

The share of renewable energy in the mix is progressing, and today numbers such as 20% are becoming usual, with more and more countries or regions seeing their share above 50% or even sometimes 100% during short period (**see Fig. 2**). This is explained by the incredible, super-fast decrease of their costs, the technological improvements, particular impressive for solar PV, and a better understanding of the integration of these technologies in our energy systems. **Fig. 1** shows the different LCOE for the main technologies used today to produce electricity, solar PV and wind being the lowest, below 40USD/kWh (vs 68 USD and 112 respectively for gas and coal).

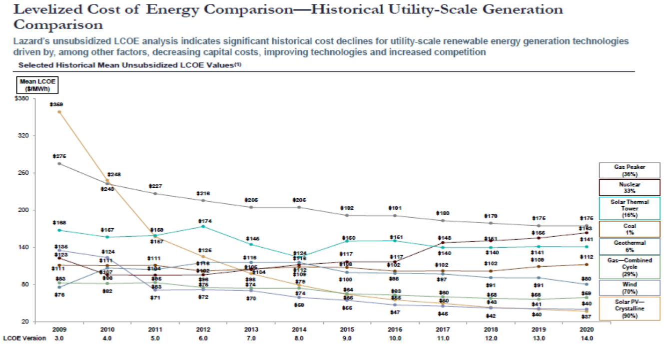


Fig. 1 Selected historical mean costs by technology
The World Nuclear Industry – Status report 2019

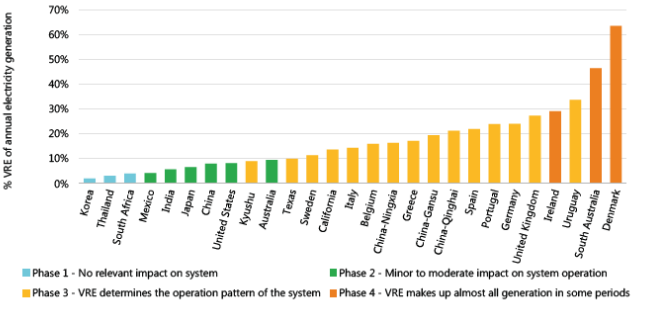


Fig. 2: Annual VRE share & corresponding system integration phase in selected countries/regions in 2018
AIE – Status of Power System Transformation 2019

Many countries are searching for the right approach to decarbonize their energy systems and remain cautious about renewable taking the lead too quickly. One of the reasons, aside from lobbying actions with different interests, may be that they are still unclear about how to solve some of the challenges these technologies pose, such as intermittency, raw-material constraints and geopolitical dependency.

However, if properly addressed, these challenges can be overcome and even transformed into economic opportunities. Today we will discuss the first challenge: Intermittency. In the article, the term “intermittent renewable energy”, or “REi”, will refer to solar and wind technologies.

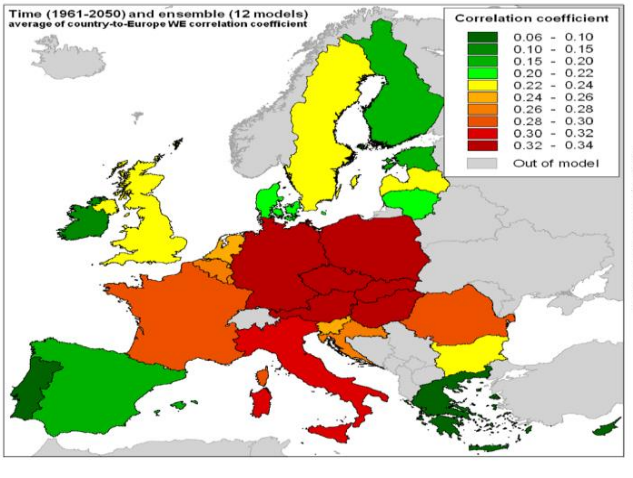
Intermittency: Definition

<u>What is intermittency and can we predict it?</u>

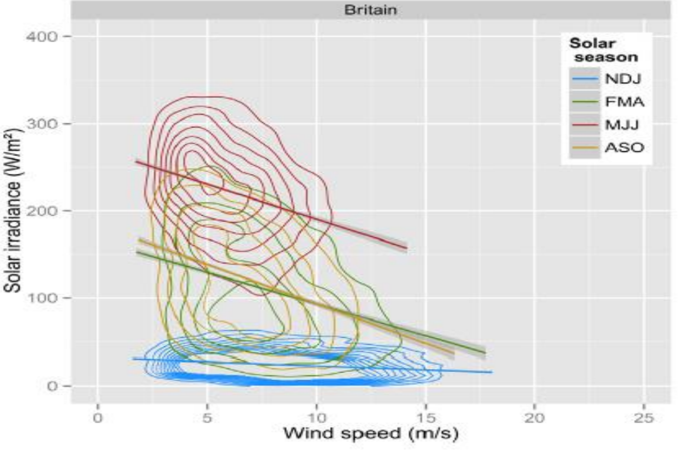
Wind and solar farms production depends on the intensity of wind and light captured by these devices. Regarding the solar resource, it mostly depends on the altitude and longitude, as well as the nebulosity (which is shown on satellite data). It is not site-specific, except if some surroundings can cast shadow on the site, so by having both data from ground weather stations, even several kms away from the site - there is an existing network of stations installed pretty much everywhere in the world, owned by universities, institutions, public organizations, research or weather centers - and satellite data, it is possible to re-create the solar radiation pattern on the specific site and estimate the production. The results are presented with their probability. For example, a 20-year P50 means "the probability to have a 50% chance to have a higher yearly resource for the next 20 years".

In general, wind resources have a higher volatility, and therefore the standard deviation is higher, leadingto a greater difference between P90 and P50 than solar PV.

Volatility of wind and solar are usually lower as you consider a higher number of sites disseminated in a larger area, in particular if this larger area includes different climate patterns (see **<u>Fig. 3</u>**). Offshore wind speed and direction are more consistent, and therefore present a lower standard deviation. Depending on the region, wind and solar can have complementary patterns (see **<u>Fig. 4</u>**), and therefore developing on-shore, off-shore and solar PV disseminated on a large interconnected area, allows a good improvement of the overall capacity factor.



<u>Fig. 3</u>: Country-to-Europe correlation factors for EU countries. The figure shows time (1961–2050) and ensemble (12models) mean values.
F.Monforti, M.Gaetani, E.Vignati - How synchronous is wind energy production among European countries? (2015)



<u>Fig. 4</u>: The joint distribution between daily-mean wind speed at 60 m, and downwelling shortwave irradiance at the surface, averaged over Britain
Philip E. Bett, Hazel E. Thornton: The climatological relationships between wind and solar energy supply in Britain (2015)

Grid Flexibility

To quote the IRENA report "By using the significant processing power afforded by modern ICT, such as cloud-based computing, improved mathematical models (which produce forecast results for 5 or 15 minutes instead of an hour) and artificial intelligence, together with the big data collected on past weather patterns and generation outputs, accuracy and locational resolution of VRE generation forecast could be improved". Fig. 5 presents some examples of implemented initiatives which have produced outstanding results

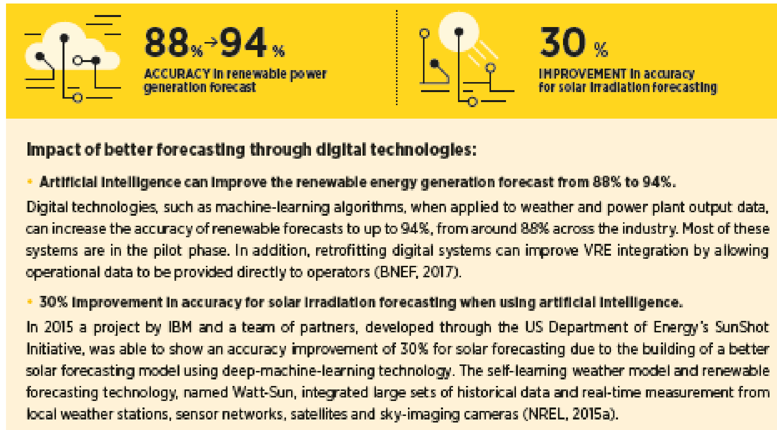


Fig. 5: Innovation landscape for a renewable-powered future – solutions to integrate variable renewables (IRENA, 2019)

What is grid flexibility?

The concept of grid flexibility has evolved over time, from the idea to adapt the energy system to any changes – in particular on the demand and generation side, or problems in the transmission lines – to today the capacity to absorb the variability created by high share of REi.

Creating grid flexibility can be done through many ways, depending on the timeframe which is considered. Indeed, intermittency can be per seconds/minutes (clouds, wind peak), days, weeks, months, seasons and so on (see Fig. 6).

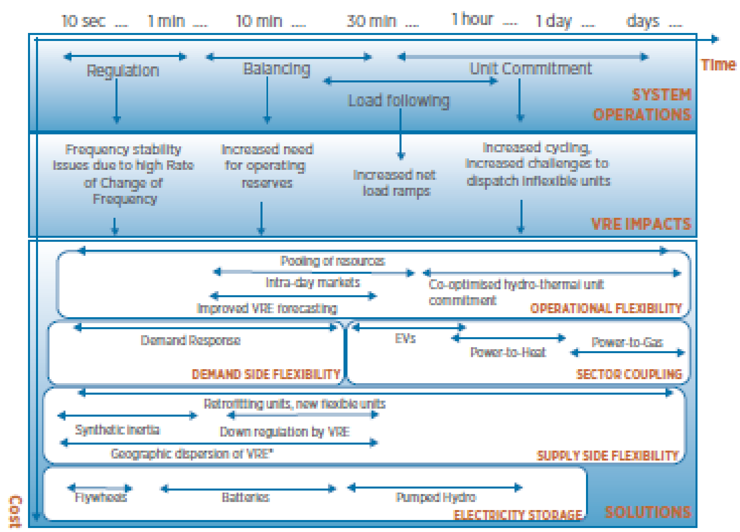


Fig. 6: Impact of REi at various time scales and different flexibility solution
IRENA Power System Flexibility for the Energy Transition – Part 1 (2018)

Among the most efficient strategies, we can mention below few examples, although flexibility can only be achieved by the implementation of all solutions available.

Grid reinforcement deferral

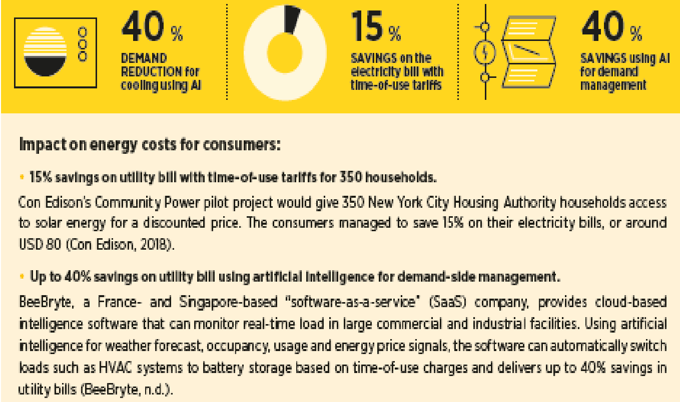
Managing variability means a better management of transportation and distribution of electricity. As indicated in the recent podcast *Redefining Energy – Episode 36: Digital Revolution in Transmission* "Modernizing and expanding the Transmission networks is one the least publicized but critical way to facilitate a faster introduction and smoother management of renewable energy".

Grid Flexibility

Some solutions exist to limit investments in expensive infrastructure, while allowing more REi to flow in the grid, such as virtual power lines, dynamic line rating or devices which can induce impedance and capacitance into specific transmission lines in a network. “Dynamic Line Rating”, implies that the capacity of the transmission lines varies dynamically according to weather conditions. In Europe for example, 11 transmission system operators have DLRs in operation. Virtual Power lines mean that batteries located at both sides of a congested part of the grid point can provide back-up energy storage during a contingency event to relieve thermal overload. RTE, the French grid operator, is piloting a project (Ringo project) that aims to install 100MW of energy storage to alleviate grid congestion and increase VRE share in the grid.

Demand-Side Management

It refers to different tools, such as digitalization of assets, automation, or market signals with different electricity prices for off-peak or peak period. The aim is to modify the pattern of the electricity consumption, with the goal to better fit to the overall generation profile and improve the forecasting of the consumption – time and quantity. **Fig. 7** presents some examples.



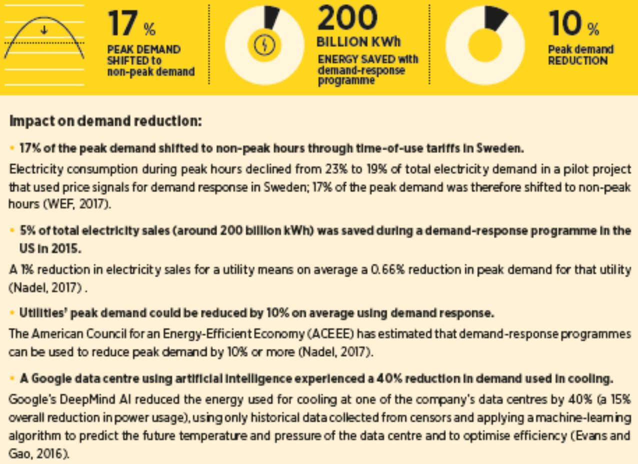


Fig. 7: Innovation landscape for a renewable-powered future – solutions to integrate variable renewables (IRENA, 2019)

Pumped Hydroelectric Storage (PHS) & Virtual Dam

More than 90% of the world’ storage capacity today comes from PHS. PHS consists in building an upper reservoir at an existing hydro plant, and whenever there is a lower demand, you can use the water flow to pump the water to the uphill reservoir, storing electricity for a later use, when the demand is higher. A virtual dam is following exactly the same principle, but instead of constructing an upper reservoir, you are using batteries to store the electricity – as there is no physical infrastructure, it is called a “virtual” dam. There is certainly a need to review the potential of PHS and Virtual Dams in our existing infrastructure. In Europe for example, depending on the environmental constraints, this potential could be as high as 100TWh/y, as indicated in a study from JRC - Assessment of the European potential for pumped hydropower energy storage (2013).

Grid Flexibility

Battery Storage

In the coming decade, battery storage using Lithium will play a major role in raising the share of REi in our grids. Batteries can provide various services, such as frequency regulation, spinning reserve, demand response and so on, as indicated in **Fig. 8**.

		Description	Use Cases[1] Wholesale	Transmission & Distribution	Wholesale (PV + S)	Commercial (Standalone)	Commercial (PV + S)	Residential (PV + S)
A Wholesale	Demand Response—Wholesale	• Manages high wholesale price or emergency conditions on the grid by calling on users to reduce or shift electricity demand				✓	✓	✓
	Energy Arbitrage	• Storage of inexpensive electricity to sell later at higher prices (only evaluated in the context of a wholesale market)	✓	✓	✓			
	Frequency Regulation	• Provides immediate (four-second) power to maintain generation-load balance and prevent frequency fluctuations	✓	✓	✓	✓	✓	
	Resource Adequacy	• Provides capacity to meet generation requirements at peak loading	✓	✓	✓	✓	✓	
	Spinning/ Non-Spinning Reserves	• Maintains electricity output during unexpected contingency events (e.g., outages) immediately (spinning reserve) or within a short period of time (non-spinning reserve)	✓	✓	✓	✓	✓	
B Utility	Distribution Deferral	• Provides extra capacity to meet projected load growth for the purpose of delaying, reducing or avoiding distribution system investment		✓				
	Transmission Deferral	• Provides extra capacity to meet projected load growth for the purpose of delaying, reducing or avoiding transmission system investment		✓				
	Demand Response—Utility	• Manages high wholesale price or emergency conditions on the grid by calling on users to reduce or shift electricity demand				✓	✓	✓
C Customer	Bill Management	• Allows reduction of demand charge using battery discharge and the daily storage of electricity for use when time of use rates are highest				✓	✓	✓
	Backup Power	• Provides backup power for use by Residential and Commercial customers during grid outages				✓	✓	✓

Fig. 8: summary of potentials under the different scenarios and topologies.
Lazard – LCOE storage analysis v6.0 (2020)

Today batteries can store electricity for up to 4 hours, and 6 hours are coming. In terms of volume to be stored, it is increasing at a very fast path, and while in 2018 the Tesla 100MW/129MWh Powerpack project in Australia was the largest in the world, today in the US you find announcements of capacities such as 150MW/193.5 MWh (Tesla), or 50MW/200MWh (LS Power), 100MW/400MWh (Gateway) and portfolio of projects as large as 400MW/1600MWh (Vistra Energy). GW size battery factories are being built, and more than 500GWh/y production are planned, with around 10% dedicated to utility scale storage, the rest being directed towards the booming EV market.

Utilities are starting to assess the required volume of electricity to be stored in our future energy systems, based for example on over-sized PV capacities whose peak production, instead of being curtailed, would be used at other times of the day. In Europe for example, members of Eurelectric have indicated a need of 345GWh for 2050 for intraday balancing (see **Fig. 9**). These numbers are certainly over-estimated. On the one hand, it is difficult to make projection for such timeframe, as our energy systems and their flexibility will evolve over time. On the other hand, no other storage capacities, no nuclear energy, and no other flexibility tools, such as demand-side management, or industrial usage during peak others, have been included. Nevertheless, this estimation, supposed to cover all Europe under an unrealistic conservative scenario, demonstrates not only the feasibility, but the high value potential of these infrastructure. In 2020, the total battery capacity is above 300GWh, and it is expected to reach above 1.3TWh by 2030 (Wood MacKenzie, 2020) – a number which some industry experts expect to be reached even by 2025.

Grid Flexibility

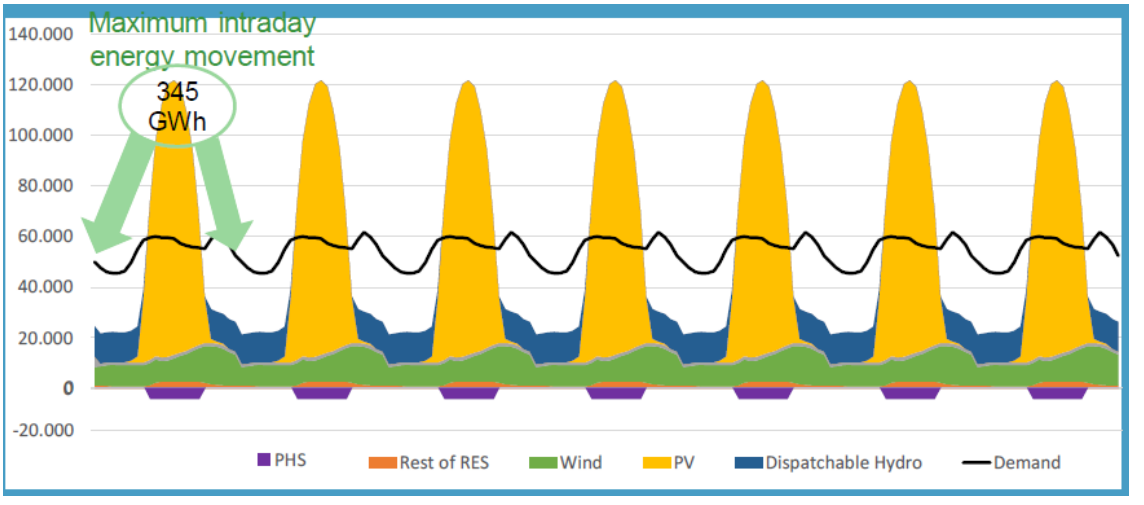


Fig. 9: hourly demand and production in a week with maximum intraday movement of energy in March 2050
Eurelectric – Charge! Deploying secure and flexible energy storage (2020)

The Role of Existing Gas Turbines

While more sophisticated, carbon free solutions are implemented, as coal is being phase out, gas will certainly temporally play an important role to balance the system. As shown in **Fig. 10**, which represent the energy mix in Germany, while CO2 emissions are drastically falling with a higher penetration of REi, there is still the need to FF capacities to balance the systems, with gas replacing coal, and with a lower capacity factor. In the future, gas turbines will either change their fuel (synthetic gas), or use CCUS, and their capacities will probably fluctuate and then decrease progressively in the coming decades.

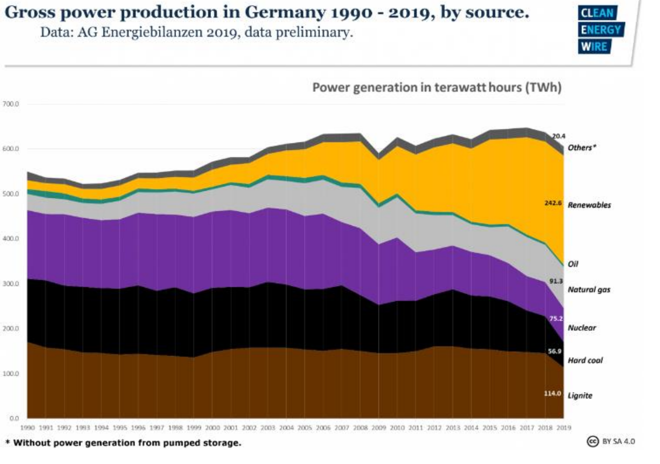


Fig. 10: Germany Energy mix 2019
Clean Energy Wire

How can we design power systems in a context of high penetration of REi, and what are the associated costs?

Step by Step approach

The criticality of intermittency depends on the share of REi in the energy mix. For example, below 10 or even 15% penetration, there is barely no investment required, and the grid operator can mostly manage it by only slightly changing the way it operates its existing infrastructure. As indicated in **Fig. 11**, different actions are required depending on the development status of Rei in the power system

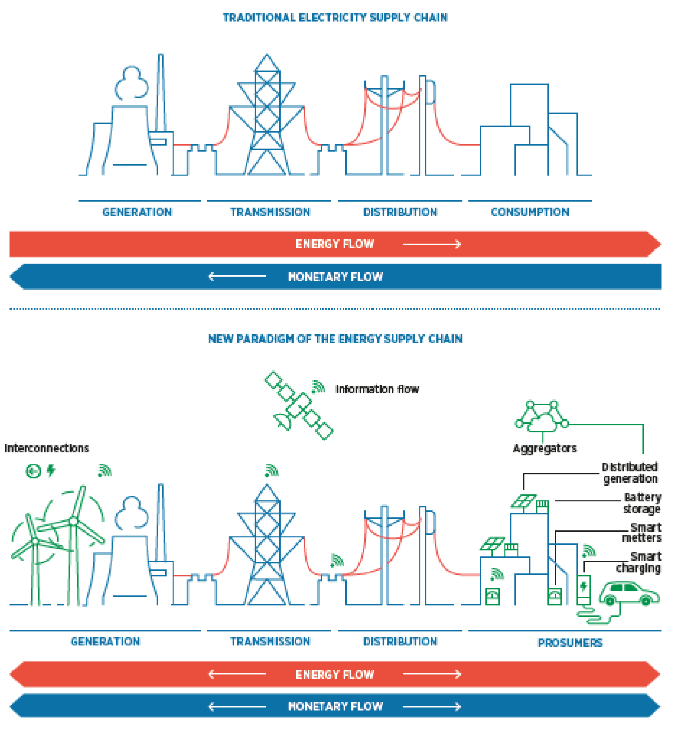
How to Design a Flexible System

Phase 1. Under 3% solar and wind. There is no noticeable impact.
Phase 2. Up to 15% solar and wind. There is noticeable impact, but this can be managed 'quite easily' by 'upgrading operational practices'.
Phase 3. Up to 25% solar and wind. This is where the first significant integration challenges are felt. It is key to focus on flexibility. The two main tools today are dispatchable power plants and the transmission grid, and increasing attention is being paid to demand side options and new storage technologies.
Phase 4. Up to 50% solar and wind. The challenges emerging at this stage are highly technical and focus on the stability of the power system. Nevertheless, they can be solved, and counties like Lithuania and Ireland are doing so.
Phase 5. Up to around 75% solar and wind. There is a structural surplus of solar and wind. It is necessary to electrify other end-use sectors to absorb it. Denmark is in this phase.
Phase 6. Getting to 100% solar and wind. This may require the conversion of electricity into chemical forms in order to offer inter-seasonal flexibility.

Fig. 11: The IEA transition framework
Carbon Tracker Initiative – Myths of the energy transition (2018)

System Modeling

A grid with an increasing share of REi is designed differently from the past centralized power systems. In the past, power plants were providing base load, and peak plants were adjusting the supply, based on the evolution of the demand, and some additional capacities were installed as back up (primary reserve, secondary reserve..). Grid operators have now to consider first the renewable energy as providing the core of the energy to supply the demand, and the remaining uncovered demand is called the residual load. **Fig. 12** shows the difference between the traditional electricity system and the new decentralized system.



The design of a grid is based today on the response to the residual load and its variability. Different scenarios are tested, and the model assesses the viability of the combination of all elements to ensure the balance between the supply and the demand.

Fig. 17: Innovation taking place in the electricity supply chain
IRENA Innovation landscape – 2019

How to Design a Flexible System

An example of a 100% renewable energy scenario is presented in **Fig. 13**, simply to shows the types of output such models can produce – here for the MENA region.

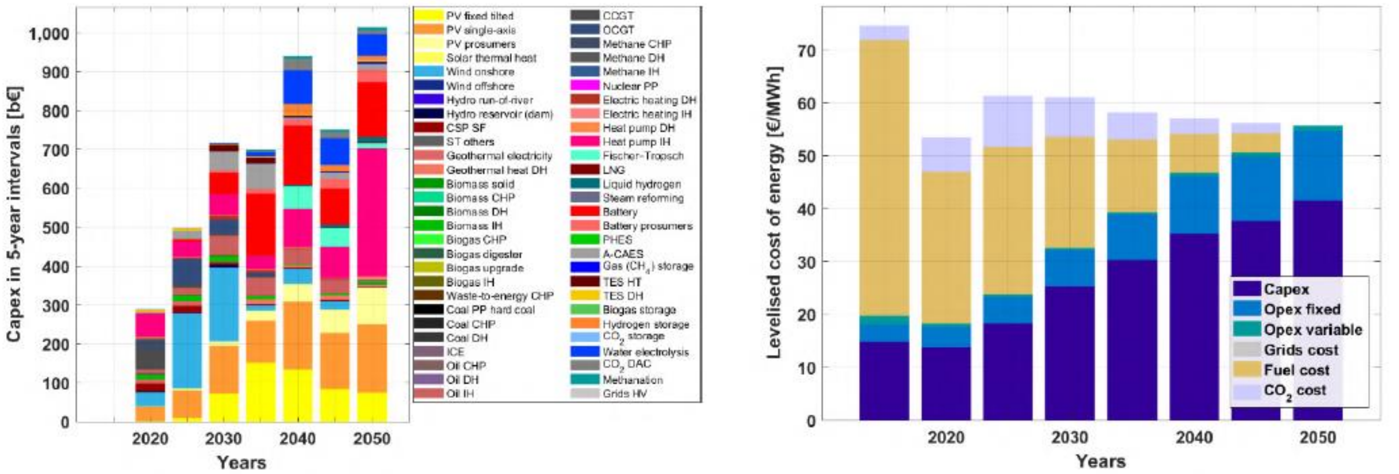


Fig. 13: MENA – Capital costs for five-year intervals (left) and levelised cost of energy (right) during the energy transition from 2015 to 2050.
Energy Watch Group / LUT - Global energy system based on 100% renewable energy (2019)

System Costs

In such a context, relying on LCOE alone is not enough to estimate the overall generation costs of the energy system. Indeed, each plant has its specific role to play in the grid, and the composition of the energy mix will greatly influence the required investment to ensure that demand and supply are well balanced, given specific constraints that grid operators want to impose on their system for security reasons. The system costs are therefore an output of the model, based on the optimization of the energy mix, and system operators can test different scenarios to see what could be the optimum.

To Summarize

- Renewable energy will become the backbone of our energy systems, which are evolving from a centralized structure to an integrated, interconnected decentralized structure
- Intermittency means variability and there is a profusion of tools to manage it
- Thermal plants are still used to balance the system, in particular gas, but their role will tend to become marginal as other technologies will become available and cost competitive.
- Grid operators can already absorb large share of Rei without making costly investments, and different tools can be gradually integrated in the system
- System design requires new skills, sophisticated modelling. The base load concept is progressively replaced by modeling the residual load.
- Countries need to better shape their policies and define their own trajectory with a step-by-step approach, in order to successfully embrace the energy transition.

About the Author

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Karim has over 15 years of experience in the energy sector, having founded and co-founded several companies providing advisory or project development services in renewable energy. He is now the Executive Director of EPDA, a renewable energy project origination platform based in Dubai. EPDA provides origination services globally for IPPs, utilities and infrastructure fund and collaborates with project owners and developers from around the world.

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