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Flexible energy system building blocks

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1 Introduction

In 2015, the Paris Agreement showed that nations worldwide consider it necessary to combat climate change. The central aim is to keep the global rise in temperature this century below 2 degrees Celsius above the pre-industrial level (see United Nations (2016)). The Conference of the Parties acknowledges enhanced deployment of renewable energy, especially in African countries.

The increased use of renewable energy sources (RES) as well as the increase of energy efficiency is crucial for the achievement of climate targets. But in 2013, electricity production worldwide was composed as follows: 67 % fossil fuels (coal, gas, oil), 11 % nuclear, 16 % hydro and 6 % other renewables (see IEA (2015)). To meet the '2ºC objective', much more capacities of RES must be installed.

The expansion of RES means transforming the whole energy system. The operation of fossil power plants is reliable and electricity output can be widely adapted to electricity demand. In contrast, the electricity production by photovoltaic and wind plants, which will in many markets be the dominant RES technologies, is dependent on weather conditions which can change quickly. As consequence, two different situations can occur on a local or central level:

1. **RES feed-in exceeds electricity demand** → other electricity producers have to limit their output and/or consumers should increase their demand
2. **RES feed-in is below electricity demand** → other electricity producers have to increase their generation and/or consumers should limit their demand

This shows that future energy systems must offer **flexibility** which can be realized on both the production and the demand side. New flexible technologies and concepts are needed in order to match fluctuating electricity production and variable electricity demand.

This report provides in Chapter 2 an overview of flexibility options in a future electricity system. In Chapter 3 we show that while this options are common to the countries, they have to develop country-tailored solutions. In Chapter 4 we discuss the different building blocks for flexibility more in detail. Chapter 5 analysis the organisation of electricity markets as an essential basis to develop country-tailored solutions. In Chapter 6 we summarise the findings and conclusions.

2 Overview of flexibility options in a future electricity system

The increasing share of RES in an energy system leads to a change of the hourly electricity production pattern. If electricity production is based on wind and solar radiation, the result is more fluctuation in electricity production which has to be balanced. This chapter gives an overview of different flexibility options that are suited to increase the flexibility of the energy system.

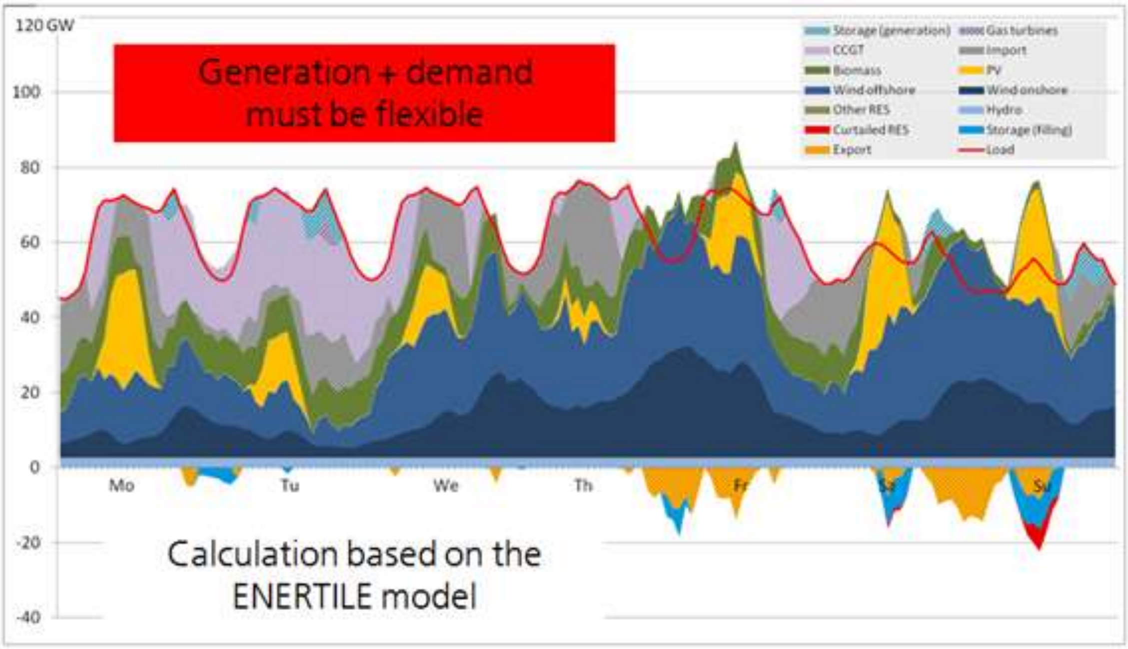
Before the different flexibility options are discussed, the meaning of flexibility has to be specified. According to Papaefthymiou et al. (2014) power system flexibility is defined as follows: *"Power systems are designed to ensure a spatial and temporal balancing of generation and consumption at all times. Power system flexibility represents the extent to which a power system can adapt electricity generation and consumption as needed to maintain system stability in a cost-effective manner.* ***Flexibility is the ability of a power system to maintain continuous service in the face of rapid and large swings in supply or demand****." (Papaefthymiou et al. (2014), p. 1)*

The main reasons for the increasing flexibility need will be presented in the following. Furthermore, flexibility options and the respective operation purposes are summarized.

2.1 Reasons for increasing flexibility need

In general, a growing share of RES leads to an increase in variation in the hourly electricity production. However, the extent of the fluctuations and the need for flexibility depend on the type of RES and on the mix of different RES technologies. Photovoltaic plants are well suited to electricity production in regions with high levels of solar radiation and the feed-in shows daily and seasonal patterns. Wind feed-in is highly correlated with wind speed and shows most irregular hourly feed-in among the various RES types. The feed-in of wind and photovoltaic plants is therefore difficult to predict, so the planning of electricity production in an electricity system depends to a large extent on feed-in forecasts that should be as precise as possible. But even if forecasts would be exact, flexible technologies are needed that can be activated for a fast ramp-up or ramp-down of electricity production or demand. However, there are also RES types that do not fluctuate. Hydro power is a very common form of renewable energy worldwide and offers almost constant electricity production (see IEA (2010)). Biomass is well controllable and is in widespread use today in Europe and North America (see IEA (2015)). Geothermal and solar thermal power plants combined with storage may allow also a constant electricity supply. The mix of the different technologies determines the final resulting electricity production pattern and the need for technologies or concepts that help to balance the fluctuating production. **Fehler! Verweisquelle konnte nicht gefunden werden.***Figure 1* shows an example of the hourly matching between supply and demand for Germany for one week in 2050 if a high share of RES is assumed.

Figure 1 Hourly electricity production mix in the German electricity system 2050 (RES share 95% in the European power mix) (source: Pfluger et al. (2011))



Besides the fluctuations on the supply side, there is also a variation of hourly electricity demand. By consequence, not only the supply, but also the demand of electricity are forecasted and supply and demand must be balanced. For the future, it is expected new technologies like electric mobility or heat pumps are entering the market and replace technologies that are based on fossil fuels. Publications show that this is needed in order to reach the emission reduction targets (see e.g. European Climate Foundation (2010)). For the integration of these new electricity consumers, it is important to develop control methods and/or tariffs that help to manage this electricity demand in order to avoid situations with high peak demand. At the same time, efficiency improvements lead to a decrease in electricity demand. By consequence, the yearly demand of a region will change as well as the hourly demand pattern.

2.2 Options for increasing flexibility in electricity markets

Different flexibility options exist that are suited to improve the energy system's flexibility. Table 1 lists these options with a short description of the operation purpose.

Table 1 Overview of flexibility options (the chapter links refer to the following chapter where more details are provided on the different options)

Flexibility option (Technical Flexibility "Enablers")	**Operation purpose**
RES generation management (4.1)	Adapt the feed-in of RES to the actual demand or grid capacity. One example is curtailing of RES which means limiting the feed-in of RES if it exceeds electricity demand or grid capacity
RES technology mix (4.1)	Mix as far as possible complementary RES technologies (limited by the available RES potentials)
Controllable power plants (fossil, biomass, solarthermal and geothermal power plants) (4.2)	Provision of electricity during periods with low RES feed-in and fast ramp-up or ramp-down in situations with strong fluctuations of RES feed-in
Extension of grid lines and interconnectors (4.3)	Spatial integration of RES by better connecting countries or regions within a country to increase balancing effects
Storage systems (4.4)	Storing electricity if RES feed-in is high and reconversion into electricity if RES feed-in is low
Demand Side Management (4.5)	Shifting electricity demand of flexible electricity consumers like electric cars, heat pumps etc. Reducing electricity demand as whole: this reduces the need for flexibility as it increases automatically the share of flexible dispatch.
Sector coupling (4.5)	Power-to-Heat: Using electricity for heat generation Power-to-Gas/Fuels/Chemicals: Using electricity for production of hydrogen or carbon-based energy carriers like methanol

Close cooperation on the regional and country level as well as coupled wholesale markets and a **high level of physical interconnection** help to increase balancing effects (Fraunhofer ISI (2013), Fraunhofer IWES (2015)). Studies show that wind and solar output is generally much less volatile within big market areas compared to smaller ones because of balancing effects (Fraunhofer ISI (2013), Fraunhofer IWES (2015)). Hence, less extreme values occur. Cross-border trading options allow that regions with high RES feed-in provide electricity for regions with low RES feed-in or different high RES supply patterns and vice versa.

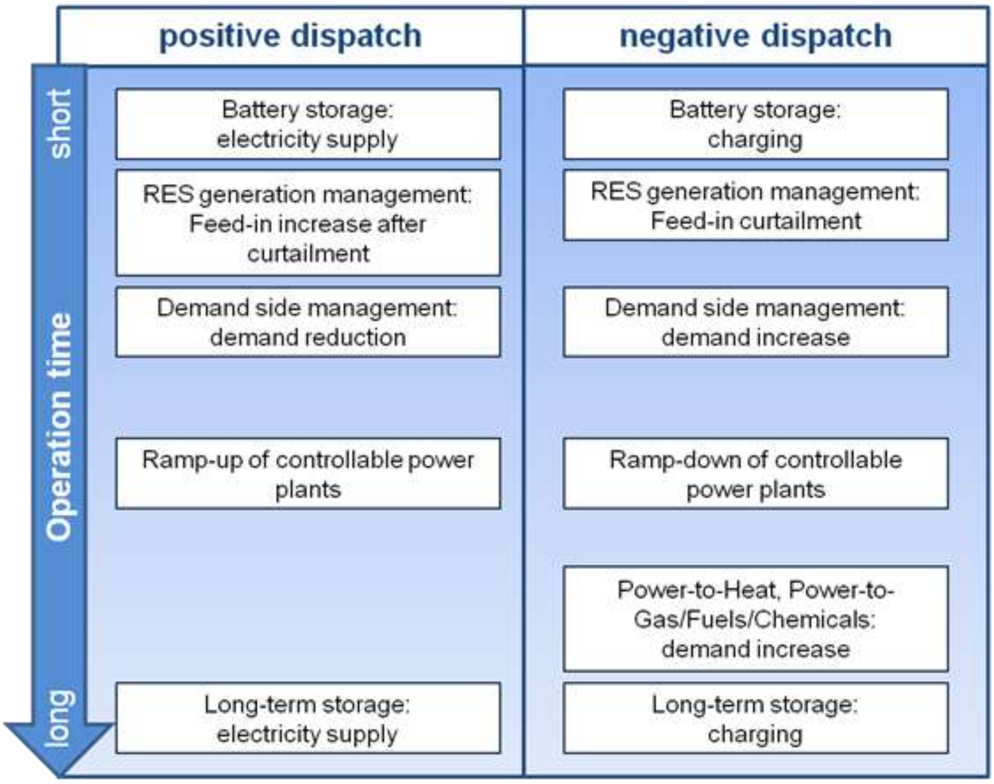
In this context, **grid infrastructure** plays also an important role for balancing supply and demand. In general, a well-developed network helps attain balancing effects and fewer other flexibility options are needed. However, grid expansion depends on the distribution of RES plants within the country or region: a centralised system needs in general more grid capacity on transport level whereas a system with many local RES plants needs a resilient distribution grid. So, planning of grid and RES expansion influences each other mutually.

Furthermore, a **mix of energy technologies** influences the need for flexibility. This applies to the combination of RES technologies as well as to the mix of fossil power plants. It depends on the geological and weather conditions of the country which mix of RES technologies is possible. But in general, challenging situations will occur in a system with high shares of RES and they require a fast response from the electrical system but also a long-term electricity generation backup if RES feed-in is low due to a lack of wind or solar radiation. Therefore, it can be assumed that a market specific mix of different flexibility options covering different time scales will be used in the future.

Demand side management (demand response and demand reduction) as well as **sector coupling** completes the spectrum of flexibility options.

Some of the flexibility options require a quick response, so technologies with fast reaction times are needed. However, in other situations, flexibility must be provided during a long period of time, so flexibility options must show a long operation time and ideally high efficiency. In Figure 2, flexibility options are arranged by typical operation times. Furthermore, the direction of the dispatch is specified.

Figure 2 Type of dispatch and typical operation time of flexibility options



A positive dispatch means that demand exceeds supply, so demand has to be lowered or additional power generation must be offered to maintain system balance. A negative dispatch means that supply exceeds demand, so electricity production must be lowered or demand of controllable loads enhanced.

As the fluctuating feed-in of RES can be balanced better within a large market area that is characterized by different geological and atmospheric conditions, the close collaboration of neighbouring countries offers frequently a highly competitive option for the provision of flexibility.

It becomes obvious from this discussion that there is not only one option which is suited to cover the flexibility demand. In most cases, a mix of various options will be needed to balance supply and demand because situations in the energy systems will have very different requirements.

2.3 Non-technical “enablers for flexibility”

There are also a variety of **non-technical “enablers for flexibility”** to be tackled (see *Table 2*):

- **Harmonised energy policies between neighbouring countries** can mean benefits for both partners as they may secure mutually supportive flexibility provision and thus increase security of supply and system stability.
- The flexibility options do not only differ with regard to their operation purpose and operation time, but also with regard to their suitability for specific locations and their costs. Thus, a **non-discriminatory market design** is a good instrument that leaves the choice and combination of the cost-efficient options to the market, especially because the flexibility options show a potential for development that is currently difficult to assess. So, the expansion of RES has to be accompanied by a market design that supports the use of flexibility options. It plays an important role in setting up the appropriate framework conditions that allow a broad use of flexibility options and a non-discriminatory access to the energy market for all flexibility options. Besides, it has to ensure security of investment. But market design options can not only influence the investment in flexible technologies but also promote international trading that increases the overall system’s flexibility too (see Papaefthymiou et al. (2014)).
- **Acceptance:** the cooperation at policy level has to be accompanied by physically implementing grid capacity and interconnectors. First experiences show however, that the expansion of grid lines, power plants and RES finds only little or no acceptance e.g. in some regions of Germany. Therefore, companies but also politicians are obliged to involve citizens in this transformation process at an early stage in terms of communication, discussion panels and participation. This process should not only target the information of residents and the broad public, but also involve citizens in the implementation process and take their

considerations seriously. For that reason, very recently, underground cables have become favourite in Germany despite much higher cost.

- Finally, **refining the methodologies for forecast and monitor fluctuating RES** reduces projection errors and the need to balancing power.

Table 2 Overview of flexibility support (non-technical flexibility enablers) (the chapter links refer to the following chapter where more details are provided on the different options)

Flexibility support (Non-technical Flexibility “Enablers”)	**Operation purpose**
Harmonised energy policies	Secures mutually supportive flexibility provision and thus increases security of supply and system stability
Non-discriminatory market design	Leaves the choice and combination of the cost-efficient options to the market, especially because the flexibility options show a potential for development that is currently difficult to assess
Acceptance	Involve citizens in the implementation process and take their considerations seriously.
Improved monitoring and forecast methodologies for RES production	Provides more certainty for the expected production (at least at the short-term level)

3 Common flexibility elements but tailored solutions

This chapter has a view at the specific context for different countries in Europe and in MENA. Though seeking for flexibility options profits best from cooperation among countries, in particular from the interconnection of neighboring country but also with more distant regions, there are **country specifics to be considered when developing flexibility options**. This may concern:

- The **geographic location** of the country with respect to possible cooperation partners;
- The **RES technology mix** available for a country (technology rich or technology poor country), taking into account technology cost;
- The **degree of cooperation** with adjacent and more far distant countries, in particular on interconnections;
- The **possibility to export** large shares of production;
- The **availability of dispatchable/storable RES;**
- **The availability of demand response and sector coupling options.**

Figure 3 to *Figure 10* present some specific country contexts (hourly demand and supply calculated with the EU-MENA energy model ENERTILE (http://www.enertile.eu/enertile-en/index.php). These cases illustrate the diversity and constraints countries are phasing, depending much also on the degree of cooperation with other countries.

The cases are briefly characterized:

- **Germany (***Figure 3* and *Figure 4***)**, central and well connected country, “technology rich”, imports from MENA allowed/not allowed: this country benefits from a favourable position in the middle of Europe and is well interconnected. There is a large mix of technologies available (solar, on-shore/off-shore wind, bio energy). Interconnection reduces the need for storage and the cost.
- **UK (***Figure 5***),** island, relatively isolated though interconnected, “technology poor” (wind on/off-shore as the main technologies). Hence the need to curtail RES in quite some contexts though demand response and sector coupling may provide additional flexibility.
- **Spain (***Figure 6***)**, southern country at the border of Europe, “technology rich”. Though the country is in a border region of Europe it can take advantage from interconnections (exports to France and the remainder of Europe) and technology mix. Storage is less required. However, this is subject to the possibility to export.
- **Romania (***Figure 7***)**, also a southern country at the border of Europe, is however, “technology poor”. The main focus is on fluctuating PV though hydro assures

some base-load. Given that storage from CSP is no available and other storage costly, the remaining load may be covered by flexible fossil fuels such as gas.

- **Norway** (*Figure 8*), a northern country well interconnected with neighbours, “technology poor” but with high flexible RES share, can act as a net exporter of RES, stabilizing thus the own electricity system.
- **Morocco** (*Figure 9*), southern country at the border of Maghreb close to Europe, “technology rich” (wind on-shore, solar PV, solar CSP), imports from MENA to Europe allowed (mainly cheap wind energy). Morocco could profit from exports and dimension the electricity system in such a manner, that the fluctuations in the own electricity system are limited. N case that Morocco could not export, the design of the system be quite different and the need for storage CSP or other storage is large increased (as long as interconnection with the neighbors is not increased). However, given the position of Morocco at the border of the Maghreb, this may be more limited.
- **Saudia Arabia** (*Figure 10*), southern country at the border of MENA far from Europe (hence little contribution from exports) , “technology poor” (mainly solar). The need for storage is high, hence large contributions from solar CSP.

*Figure 3 Matching supply and demand with flexibility (Germany, **central and well connected country, “technology rich”,** imports from MENA **allowed**, calendar week 10 in 2050) (source: Fraunhofer ISI (2013), ENERTILE www.enertile.eu)*

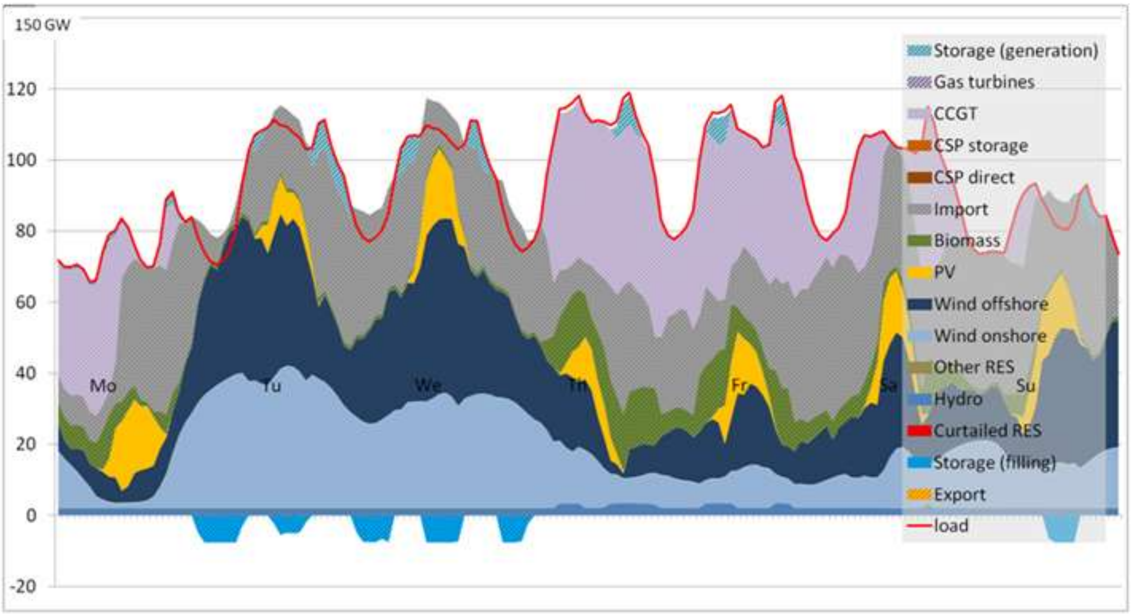


*Figure 4 Matching supply and demand with flexibility (Germany, **central and well connected country, “technology rich”,** imports from MENA **not allowed**, calendar week 42 in 2050) (source: Pfluger et al. (2011), ENERTILE www.enertile.eu)*

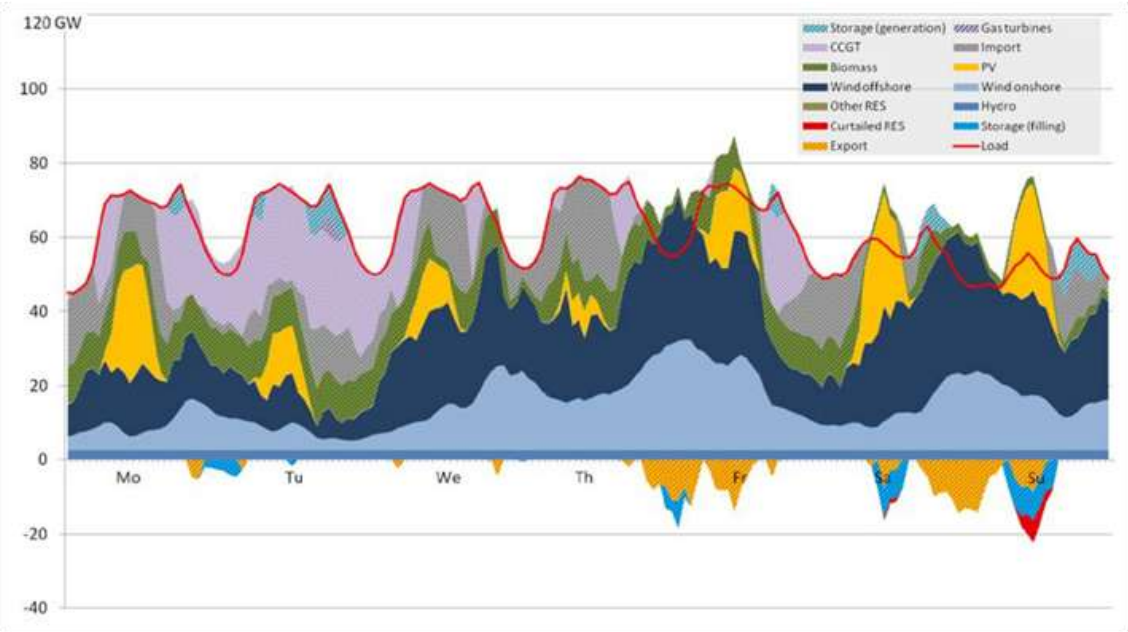


*Figure 5 Matching supply and demand with flexibility (UK, **island, relatively isolated though interconnected, “technology poor”,** imports from MENA **allowed**, calendar week 9 in 2050) (source: Fraunhofer ISI (2013), ENERTILE www.enertile.eu)*

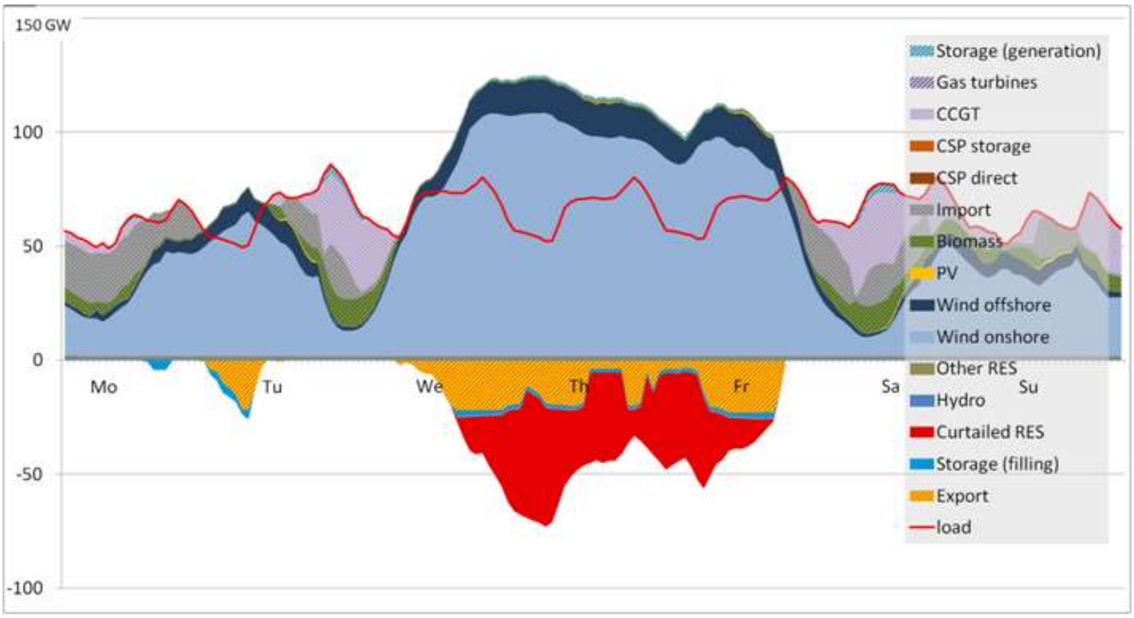


*Figure 6 Matching supply and demand with flexibility (Spain, **southern country at the border of Europe, “technology rich”,** imports from MENA **not allowed**, **net exporter,** calendar week 27 in 2050) (source: Pfluger et al. (2011), ENERTILE www.enertile.eu)*

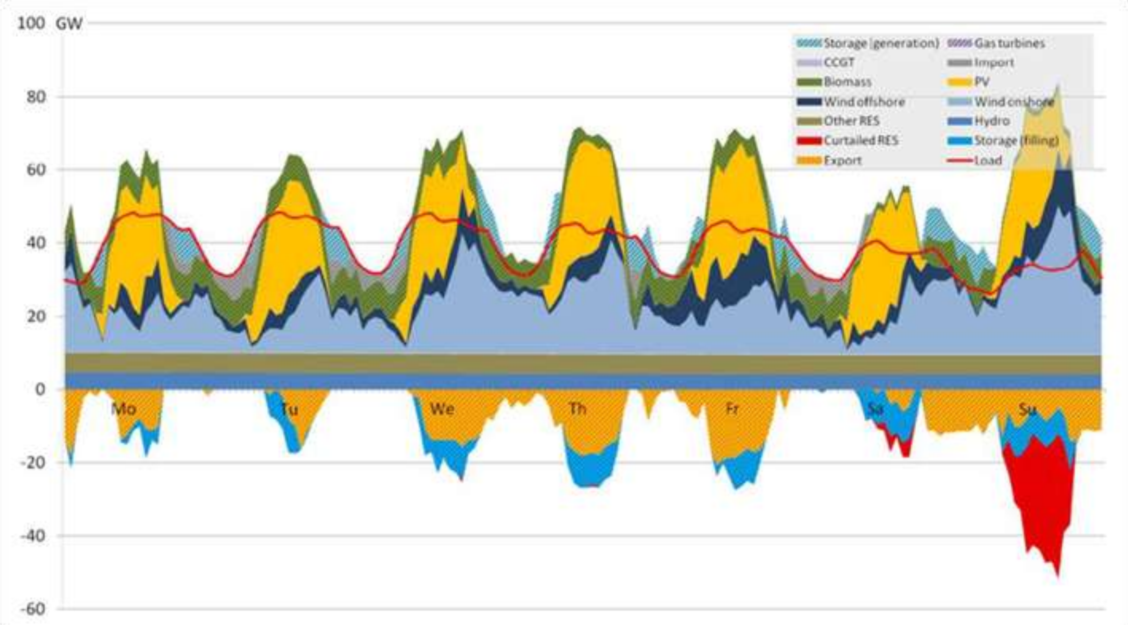


*Figure 7 Matching supply and demand with flexibility (Romania, **southern country at the border of Europe, "technology poor",** imports from MENA **not allowed**, **no net exporter,** calendar week 29 in 2050) (source: Pfluger et al. (2011), ENERTILE www.enertile.eu)*

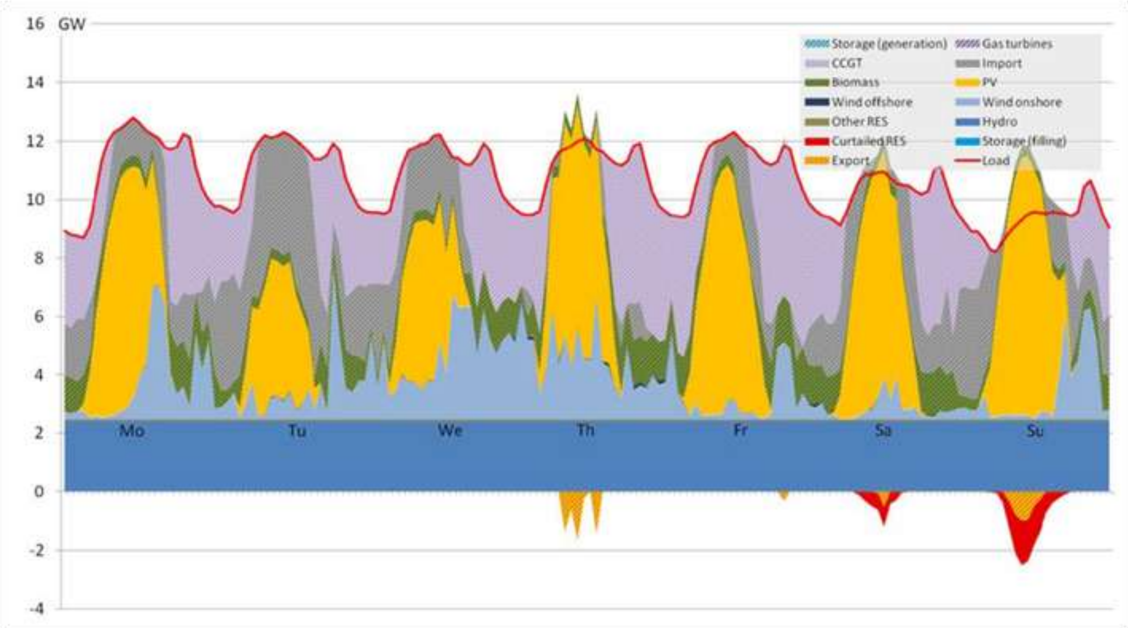


*Figure 8 Matching supply and demand with flexibility (Norway, **northern country well interconnected with neighbours**, **"technology poor", high flexible RES share,** imports from MENA **not allowed, net exporter,** calendar week 29 in 2050) (source: Pfluger et al. (2011), ENERTILE www.enertile.eu)*

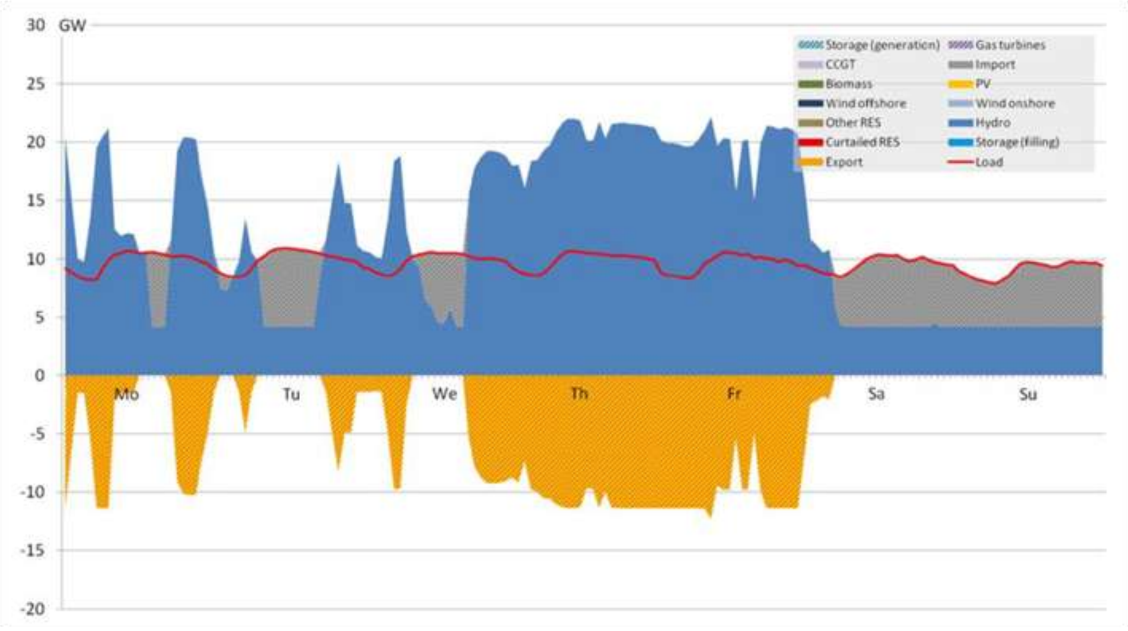


*Figure 9 Matching supply and demand with flexibility (Morocco, **southern country at the border of Maghreb close to Europe, “technology rich”,** exports from MENA to Europe **allowed**, calendar week 32 in 2050) (source: Fraunhofer ISI (2013), ENERTILE www.enertile.eu)*

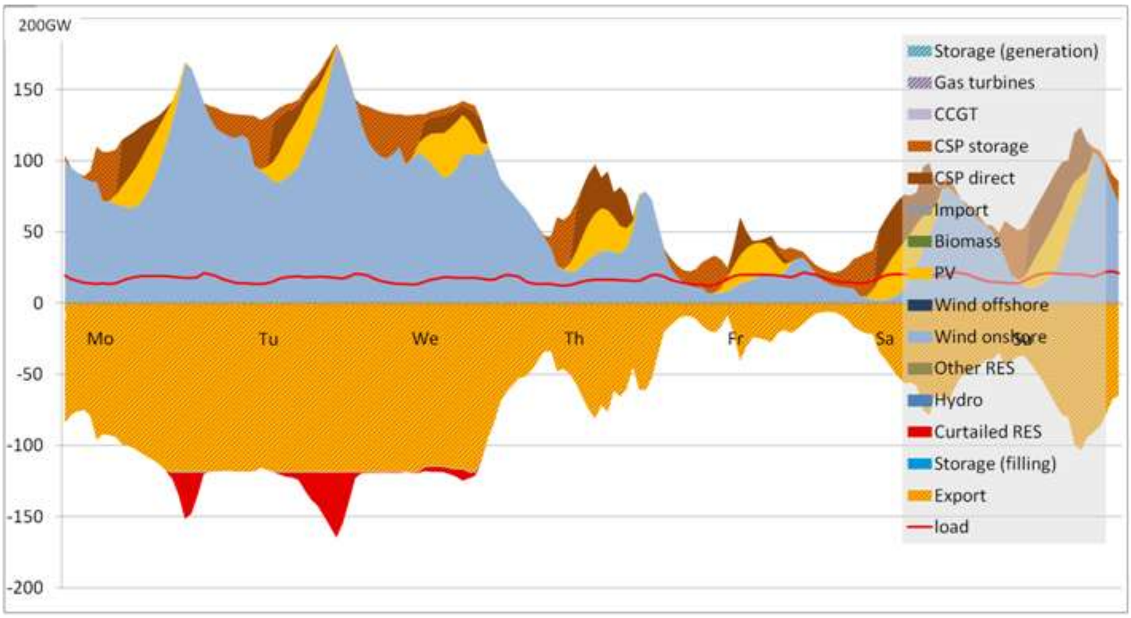
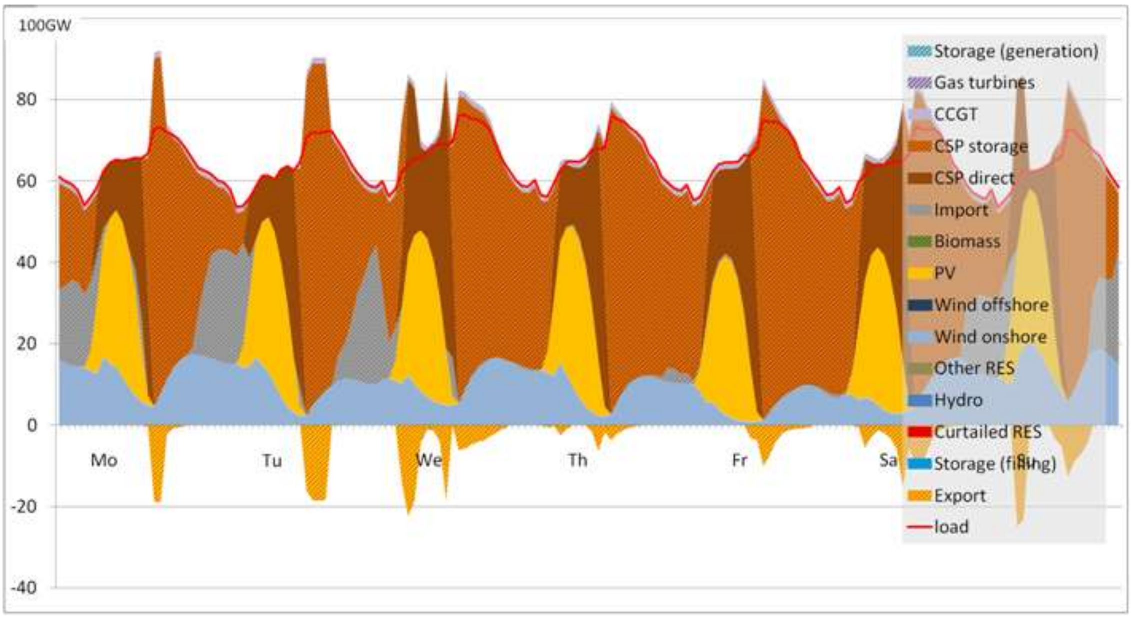


*Figure 10 Matching supply and demand with flexibility (Saudia Arabia, **southern country at the border of MENA far from Europe, “technology poor”,** exports from MENA to Europe **allowed**, calendar week 48 in 2050) (source: Fraunhofer ISI (2013), ENERTILE www.enertile.eu)*



4 Building blocks for a flexible and cost efficient renewable energy-based system

This chapter discusses more in detail some of the buildings blocks for a flexible and cost efficient renewable energy-based system, for which an overview was provided in the previous chapter.

Technical and economic figures will be compared and benefits and challenges for the system integration will be pointed out. However, the detailed exemplification in system approaches is the task of a future work.

4.1 Contribution of RES to the provision of flexibility

A growing share of RES is the main reason for the increasing flexibility need. See Annex 1 for an overview of recent developments of RES and their cost.

If RES plants themselves could provide flexibility, this would be a great benefit, especially for systems with high shares of RES. RES operators can cause a flexible operation by adjusting the plants' power production and thus contribute to balancing the system generation and load or to congestion management. The technical characteristics of wind turbines and photovoltaic plants allow a quick reaction to control signals, so they can be curtailed which means a down regulation within seconds. An up regulation is also possible and can be realized by limiting the output below the possible feed-in followed by a selective increase to the normal level as needed. However, both operations reduce the overall output of RES, so in general, for economic and climate reasons it is preferred to use this RES feed-in or at least to store it compared to a down-regulation of fluctuating feed-in.

Even if the active power control of RES plants is possible from a technical point of view, there are some challenges with regard to the implementation of control measures for RES. One limitation is the need for a communication and IT infrastructure between grid operators and the power plant. Furthermore, regulatory and market conditions have to be designed in a way that does not impede the use of the RES flexibility potential. If support schemes exist that remunerate the RES feed-in, the RES plant owner has no incentive to curtail the power output. More generally, it has to be considered that the flexibility potential of RES is uncertain as the feed-in of wind and photovoltaic plants is fluctuating. So, compared to other flexibility options, the provision of flexibility by RES is more difficult to handle (see Papaefthymiou et al. (2014)). However, it is a huge benefit if RES plants are well controllable because it may lower the need for other flexibility options that could be more cost intensive. So, under the precondition that there is a market design that considers not only feed-in but also curtailment of RES, it should be analyzed what costs occur for building up an IT-infrastructure for the active power control of RES plants compared to investments in other flexibility options.

Besides fluctuating RES, biogas offers the possibility to provide flexibility as it can be ramped up and down within seconds. In general, biogas plants run continuously because biogas production is a steady process. But in combination with biogas storage, power generation is less dependent on the biogas production process and can be deferred to hours with a low feed-in of fluctuating RES. Typical storage capacities allow a production shift of 3 to 6 hours (see Papaefthymiou et al. (2014) for more details). But in this case too, market conditions have to set incentives for shifting the power output. In many studies that evaluate the future development of Energy systems, dispatchable technologies e.g. CSP, gasturbines, biomass, hydro dams are used to cover the demand that cannot be met by the fluctuating RES like wind and photovoltaic (see Zickfeld et al. (2012)). However, the use of biomass for the power sector depends on the local potential for biomass and the need for biomass based fuels in the heat, transport and industrial sector. There is a competition between use of biomass for electricity production and other possible uses and from today's perspective it is expected that biomass will play an important role in the heat and transport sector and a limited role in the power sector (see Müller et al. (2015) and IRENA (2014)).

A further RES technology that can be used for a controlled provision of electricity is a concentrated solar thermal power plant. Even if those plants depend on solar radiation, thermal energy storage can be integrated (e.g. molten salt storage) which allows to provide electricity during cloud course or night. In contrast to electricity storage, thermal storage is less cost-intensive. The power output of concentrated solar power plants is defined by the size of the solar field, storage capacity and the turbine. With regard to flexibility, solar thermal power plants need one or two hours for a cold start-up and 15 minutes for a hot start-up process. Minimum load amounts to 25% of nominal load and load changes to 3% of nominal load per minute (see Pitz-Paal and Elsner (2015)). Compared to values of fossil power plants in *Table 3*, solar thermal plants show a higher flexibility potential for some criteria. The development of CSP showed a clear increase in installed capacities since 2005, but market penetration has been slower than expected. In the short term, decreasing prices for photovoltaic and wind and uncertain national energy policies dampen the development of CSP. But in the mid- to long-term, a steadier growth is expected because of more robust policies and ambitious targets for RES expansion. Furthermore, energy security plays an important role for countries that lack indigenous fossil fuels or have a rising demand for cheap energy, mainly due to growth population (see CSP Today (2015)). Additionally, the project DESERTEC analysed the provision of electricity (mainly by CSP) by North African states for Europe and showed that an intercontinental electricity network can have socio-economic and cost advantages compared to local production and consumption photovoltaic (see Zickfeld et al. (2012)). So, it is assumed that CSP will play an important role in the future – not only for electricity generation but also for balancing fluctuating RES feed-in of wind and photovoltaic plants beyond the background of ambitious climate targets.

4.2 Fossil-fuelled plants

With increasing shares of RES, thermal generation takes the role of back-up capacities to cover the variability of RES and demand. Fossil-fuelled plants, mainly based on coal, gas and oil, are controllable to a certain extent and can offer some flexibility to the system. However not all types of power plants show the same flexibility potential. The key criteria listed up in Table 3 help to describe the technical restrictions that limit the flexibility of different types of power plants.

Table 3 Technical and economic parameter of fossil power plants (average values, source: Görner and Sauer (2016); Statista (2016))

Criteria	**Unit**	**Steam turbine power plant**			**Gas turbine power plant** (300 MW)	**Combined-cycle gas turbine plant** (600 MW)
		Hard coal (600 MW)	**Lignite** (600 MW)	**Oil** (300 MW)		
Efficiency	%	40	37	42	35	55
Minimum load	% of nominal power	40	50	15	28	53
Load gradient	% of nominal power / minute	3	3	4	105	5
Start-up time (cold)	hours	4	4,5	3	0,15	3
Start-up time (hot)	hours	2	2	1	0,15	1
CO_2-Emissions	g CO_2/kWh	342	410	300	202	202
Specific Investment	Mio. EUR/GW	1,500 (2023)	2,100 (2023)	Case specific	375 (2023)	700 (2023)
Specific Investment for retrofit of existing plants	Mio. EUR/GW	75 (2023)	70 (2023)	Case specific	Case specific	700 (2023)
Fuel price (2013)	EUR/MWh	11.4	1.6	58.3	28.7	28.7

It becomes clear that gas turbines show the highest load gradients and fastest start-up times among the considered technologies. Furthermore, they emit a relatively low amount of CO_2 during operation compared to oil and coal. The disadvantage today lies within the dependence on the fuel price of natural gas which is currently approximately three times as high as the coal price and a multiple of the lignite price. For this reason, variable electricity generation costs of gas turbines exceed actually those of coal and lignite power plants today. However, this may change in the future.

In general, the flexible operation of fossil-fuelled plants means more frequent start-up procedures and part-load operation which is linked to lower efficiency and higher CO_2-emissions. Furthermore, wear and tear increases and leads to higher maintenance costs. Power plants that would be built today show a higher flexibility potential than existing plants of which some are in operation for some decades already. However it is cost-intensive to replace old by new power plants and in some countries, they lack public support for reasons of health or climate protection. Therefore, retrofit measures could upgrade the flexibility characteristics of existing power plants, decrease minimum load and increase the controllability. *Table 3* shows that especially for hard coal and lignite, the specific investment for retrofit is much lower than an investment in a new plant. In the future, especially flexible gas turbines could be a good complement for RES, in the long term possibly in combination with carbon capture and storage for avoiding the emission of CO_2.

4.2.1 Coal-fired power plants

In the past, hard coal-fired power plants were used for covering the base load which means that they were under constant operation and rarely shut down. The installations were optimized with regard to maximum load, nominal efficiency and maximum lifetime under the constraints that operating costs and CO_2 emissions should be minimal. There was no need for a more flexible operation. In the future, the priorities will change and the development of power plants has to put a stronger effort on flexibility criteria which contains the increase of efficiencies in partial load and a better minimum load operation. The success of coal plants will depend on the ability of finding a technical and economical optimum that enables an economically viable operation under new market conditions. In general, there exist some game changers that would accelerate the declining use of coal power plants: high prices for CO_2 certificates, regulatory laws on CO_2 limits, missing market incentives for fossil power plants and protracted approval procedures for new investments. But from today’s perspective it is expected that fossil power plants play an important role in the short and mid-term but their use will decrease in the long term when ambitious RES shares above 80% shall be realized. During the transition period from a fossil based to a RES based energy system, old coal fired plants could be used as back up capacity. This would mean that they are only used in situations that show critical security of supply. In this way, CO_2 emissions by coal combustion could be limited, because operating times would be smaller than today, but power plants could be used for maintain the system’s stability. The difficulty lies within the implementation and design of an appropriate financial remuneration that has to be paid for the provision of back up capacity.

4.2.2 Gas-fired power plants

Because of their characteristics that show a high flexibility potential, gas-fired power plants are predestined for offering balancing power. In the technical development, main goals are the increase of efficiency but also the lowering of minimum load and the integration of heat storage for combined heat and power plants. They show a high potential for development. However, the economic efficiency of gas turbines mainly depends on the gas price, so investments in new gas-fired plants are linked to the gas price and market incentives. In the past, gas power plants were mainly used for covering peak (gas turbines) and medium load (combined cycle plants) whereas coal plants were used to supply electricity for base load. With growing shares of RES, the function of gas-fired plants changes and consist of the provision of residual load (= demand that remains after RES feed-in), balancing power, reactive power and frequency stabilization for the electricity grid. As gas-fired power plants are able for cold starts, they can provide electricity very quickly. The new supply tasks place new requirements on existing power plants in terms of more load changes and start up processes, shorter ramp-up and ramp-down times, shorter downtimes, a smaller minimum load and higher part load efficiencies.

Besides the technical characteristics, one main reason that is in favour of the stronger use of gas-fired power plants is the lower CO_2 emission factor compared to coal power plants. For reaching the climate goals, the use of gas instead of coal for electricity generation by fossil power plants most likely will play a decisive role.

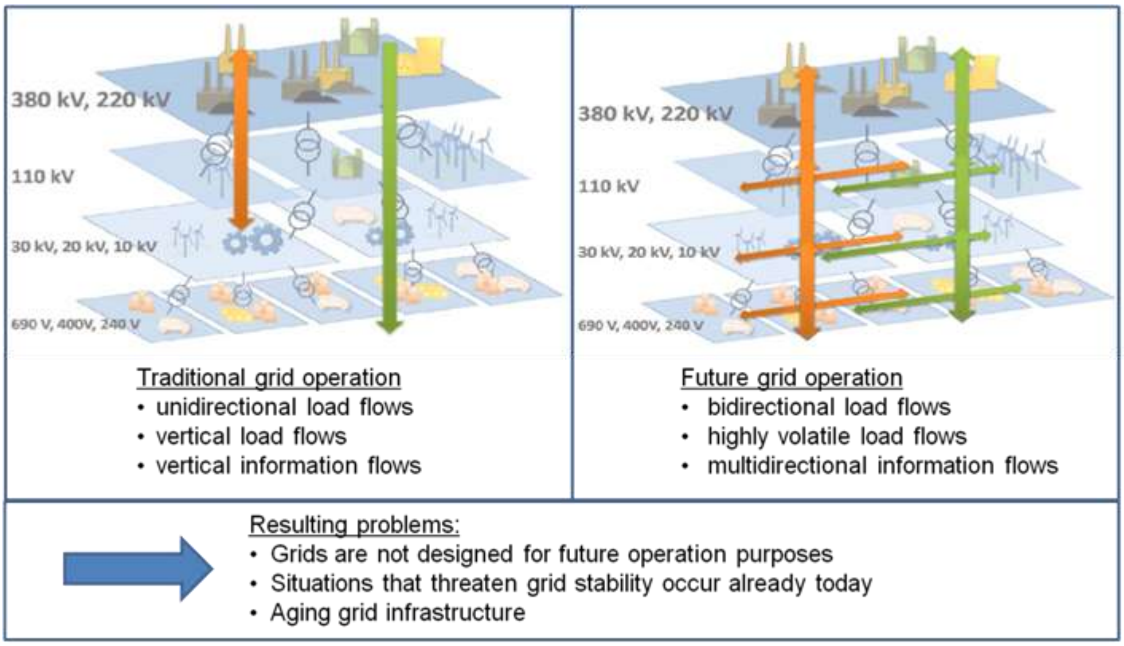
4.3 Electricity grid

Due to the technological transformation during the last decade, a large number of new technologies have become available to provide and consume electrical power. Technologies such as electric vehicles and heat pumps on the demand side but also photovoltaic and wind power on the supply side change the way electrical energy is generated and consumed. All these technologies are connected to electrical grids and trigger also changes within existing grid infrastructures (see Verzijlbergh 2013). Figure 11 illustrates the structure of the traditional and the future electricity grid.

The increasing share of RES that is installed on a decentralised level leads to reverse load flows compared to the traditional system. Furthermore, long distances between RES feed-in and consumers can occur if RES potentials are attractive in areas that are far away from regions with high demand.

In the following subchapters, the main technical characteristics of electricity grids and the difference between a centralised and a decentralised approach to organising grids are described. Following this an overview of available technologies is given which can be used to achieve a stable and reliable grid operation and which can be part of smart grids.

Figure 11 Transformation and resulting challenges for the electricity grid (source: Wietschel et al. (2010))



Traditional grid operation
- unidirectional load flows
- vertical load flows
- vertical information flows

Future grid operation
- bidirectional load flows
- highly volatile load flows
- multidirectional information flows

Resulting problems:
- Grids are not designed for future operation purposes
- Situations that threaten grid stability occur already today
- Aging grid infrastructure

4.3.1 Technical description of electricity grids

Electrical grids are described technically by voltages, currents, powers and energy flows. Additionally, the grid frequency is a crucial technical unit. In contrast to all other technical grid units the grid frequency is a global unit. In an interconnected grid (e.g. the European grid) the grid frequency is identical on every part of the network and on every grid level. It is influenced mainly by big loads and supply units, e.g. big thermal power plants. In contrast to the grid frequency, voltages and currents are local units which vary on the grid. For a secure network operation, all units must be kept in a specified range according to the technical standards.

Furthermore the total demand and supply in one grid region must be equal. Otherwise if feed-in is higher than demand, the grid frequency rises. If the opposite is the case the grid frequency drops. In general, supply and demand are balanced out by controlling both the demand and supply side.

4.3.2 Centralised and decentralised electrical energy systems

In central energy systems electrical energy is primarily generated by big power plants that are well controllable. The electricity always flows from central plants into the transmission grid and to a local distribution grid to which the consumers are connected. As supply and demand must permanently be balanced in electrical grids, the supply side can be used for this purpose in systems with no or little fluctuating RES power generation providing the required amount of energy (see Braun 2008).

In contrast to the central approach, electrical energy is also generated on the distribution grid level in electrical systems with high penetration rates of low scale distributed energy resources (DER). DERs are often feature-dependent RES like photovoltaic or wind power. High generation and low demand on the distribution grid level lead to inverse power flows, which means that energy flows from the distribution grid to the transmission grid. This can cause voltage drops in network elements (e.g. power lines, cables) and specific voltage bounds can be violated. The advantage of decentralised energy systems is that locally generated electricity can be consumed on-site, so less electricity transmission is necessary and distribution losses decrease (see Rotering 2011, Bayod-Rújula 2009).

4.3.3 Options for increasing the flexibility within the electricity grid

The ***cross-border expansion of the grid*** can mean the spatial sharing of flexible resources. Imbalances within a country can be compensated if grid connections are expanded. At an international level, the cross-border expansion of interconnectors ensures an increase in balancing effects as the correlation of feed-in of RES plants lowers with increasing distance. This also applies to connections across different countries. The Power Transfer Capability (PTC) between areas can be increased by a dynamic assessment of PTCs or by expanding the network. The PTC is generally defined in advance, based on forecasts and includes security margins and static line capacity limits. A dynamic assessment uses more actual data, shorter scheduling periods and allows reducing the security margins. For network expansions, two technological options are available: high-voltage alternating current (HVAC) and high-voltage direct current (HVDC). They can be realized in the form of overhead lines or underground cables which both have advantages and disadvantages. It therefore depends on which of these options fits better for a specific application (see Papaefthymiou et al. (2014)).

A large number of new technologies for ***strengthening electrical grids*** exist to ensure a stable and reliable grid operation even if flexibility requirements rise. Which options are suitable (technically and economically) depends on how the system is organised (central or decentralised) and the part of the grid which needs to be reinforced. Some of these options strengthen the grid directly and other options provide flexibility and therefore decrease the investment required for grid expansion. Conventional grid reinforcement is covered by building additional cables, overhead lines and transformers within power stations. This increases the amount of electricity the grid can transport and works for all voltage levels. In addition, there are also unconventional grid reinforcement approaches that help to handle certain challenging situations. Regulated Distribution Transformer can be used to control voltages on the local grid level. This is a cost efficient solution to deal with increased voltages due to inverse power flows in decentralised grids with high DER penetration rates. On the transmission grid level high-temperature conductors can be used instead of conventional conductors. This allows higher operating temperature levels for overhead lines and higher currents transfers. Power is voltage multiplied by current and therefore higher currents also lead to higher power and energy flows over the part of the grid where this technology is installed. Another unconventional reinforcement approach contains flexible alternative current transmission systems (FACTSs). Power flow control options like FACTS and Phase-Shifting Transformers can redirect the power through alternative pathways in specific network points. This approach is primarily used on the transmission grid level. Nevertheless, Voltage Controlled Distribution Transformers (VCDT) are used in lower voltage networks and can help to avoid network expansion (Hingorani 1993, Zamora 2001, Bayod-Rújula 2009, Esslinger 2012). However, costs are relatively high and efficiency depends on the characteristics of the system where it is applied (see Papaefthymiou et al. (2014)).

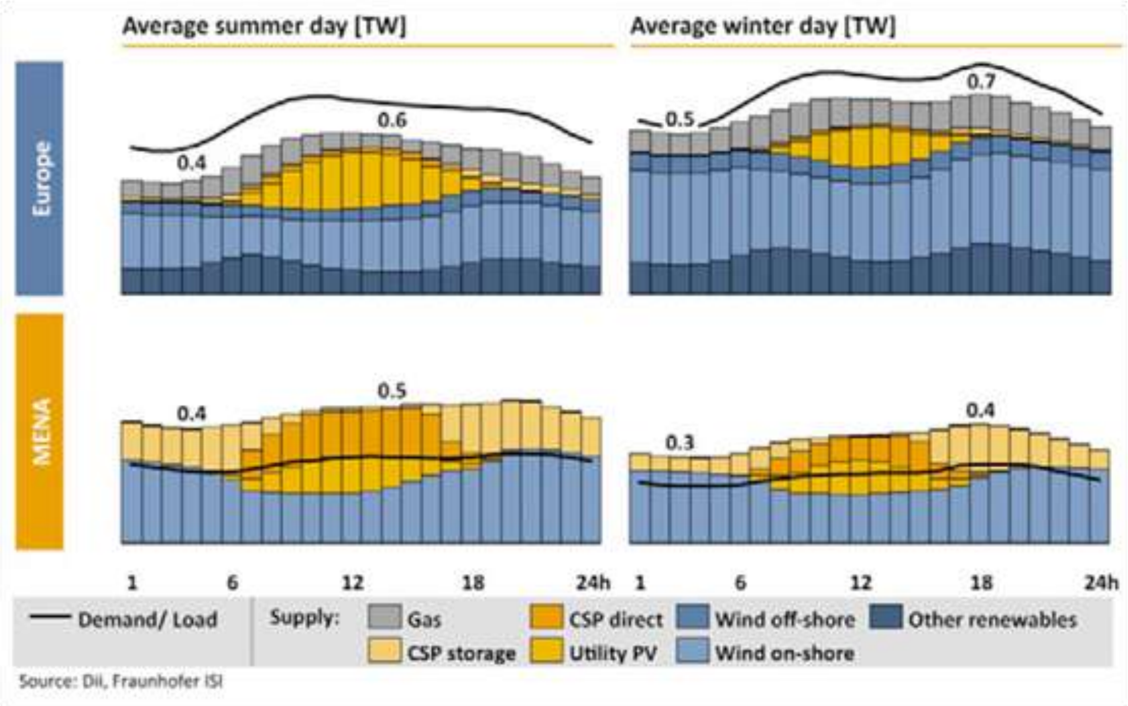
Instead of investing into the grid assets, it is also possible to ***control demand and supply of technologies which are connected to the grid*** and can influence grid units (voltages, currents, powers and energy flows) in a positive way. As described above, for a stable grid operation demand and supply must be balanced. This is done on the transmission grid level to ensure a stable grid frequency. On the distribution grid level demand and supply should also be balanced to reduce energy losses and to avoid reverse power flows which lead to high voltages. Inverse power flows can be avoided by reducing the local supply by DER or by increasing the demand during periods of high supply in that part of the grid. Vice versa in periods with high demand, flexibility can be provided by either reducing demand or by increasing supply. Additionally, DERs can be used to stabilise grid voltages. In case of high demand, power flows do not change directions and this can be solved by reinforcing the grid.

Another possibility is to check if ***rules such as market regulations or technical standards for electricity grids can be adapted*** in order to facilitate a grid operation that allows the integration of flexible units. In some countries, the liberalisation of energy markets leads to an unbundling of different actors which in turn can mean that network operators are not allowed to use energy storage. In this case it should be checked whether modifying market regulations could help to facilitate the use of flexibility options. Furthermore, technical grid standards could be extended, provided that connected technologies do not suffer any damage.

4.3.4 The effects of stronger grid connection within the DESERTEC project

Within the DESERTEC project, the effects of a stronger grid connection within the EUMENA region are analysed. The following text within this subchapter is therefore based on this publication, see Zickfeld et al. (2012). *Figure 12* reveals that there is a good fit of demand, sun and wind in the EUMENA region as a result of complementary demand and supply conditions in MENA and Europe. While load is higher in winter than in summer in Europe, the opposite is the case in MENA, where more extreme weather conditions prevail during the hot summer as opposed to Europe's cold winter. Also, while Wind production is higher in winter in Europe, it is stable throughout the year in MENA. Due to its high Solar yield, MENA is able to provide Europe with the power it needs during the summer, following the daily demand curve with the help of the CSP storage.

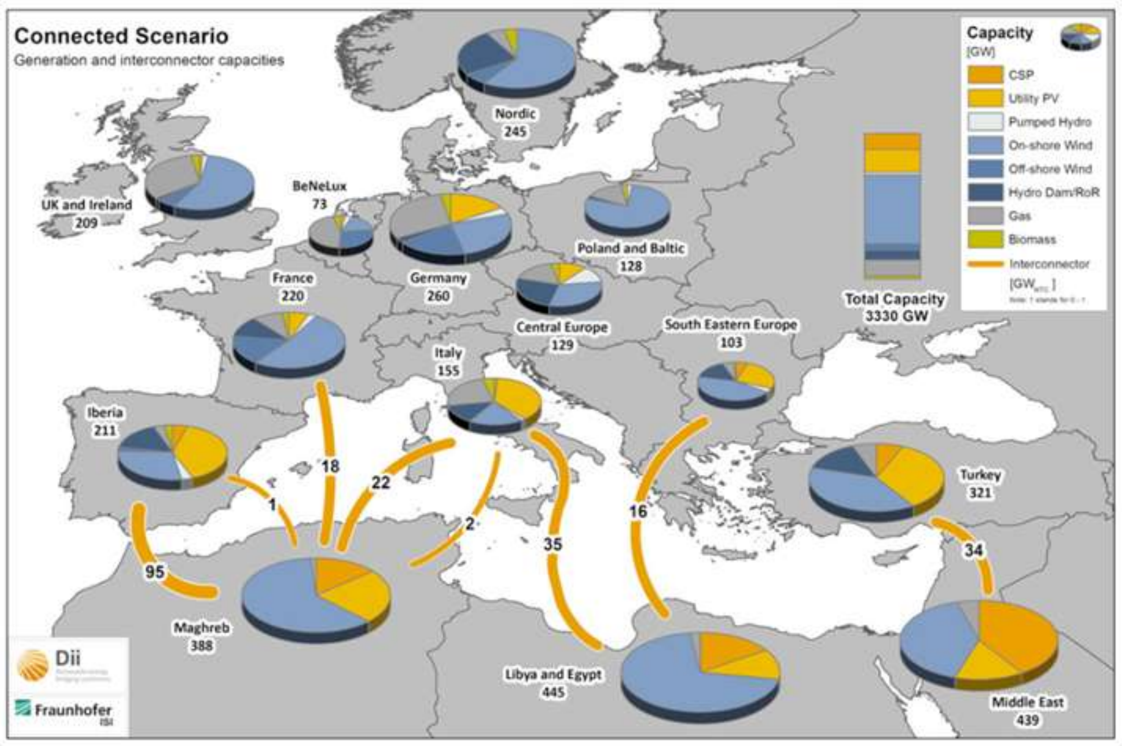
Figure 12 Daily and seasonal demand and supply in Europe and MENA (source: Zickfeld et al. (2012))



Source: Dii, Fraunhofer ISI

Two scenarios are compared within the DESERTEC project: the Connected Scenario examines a power system with full, EUMENA-wide integration (but a minimum 70% self-supply rate has been imposed on a national basis) whereas the Reference Scenario depicts a situation where each region, Europe and MENA, is fully optimized in itself and without cooperation. *Figure 13* shows the resulting grid capacities that are built if a cost minimisation approach is applied to the EUMENA region for the Connected Scenario. The connections between Maghreb and Iberia, Middle East and Turkey as well as between Libya/Egypt and Italy are significantly expanded. This results in a power exchange of 1.087 TWh (MENA/Europe) and 23 TWh (Europe/MENA)

Figure 13 Generation and interconnector capacity, Connected Scenario (source: Zickfeld et al. (2012))



The results show that a power system based on more than 90% renewable energy is technically possible and economically viable:

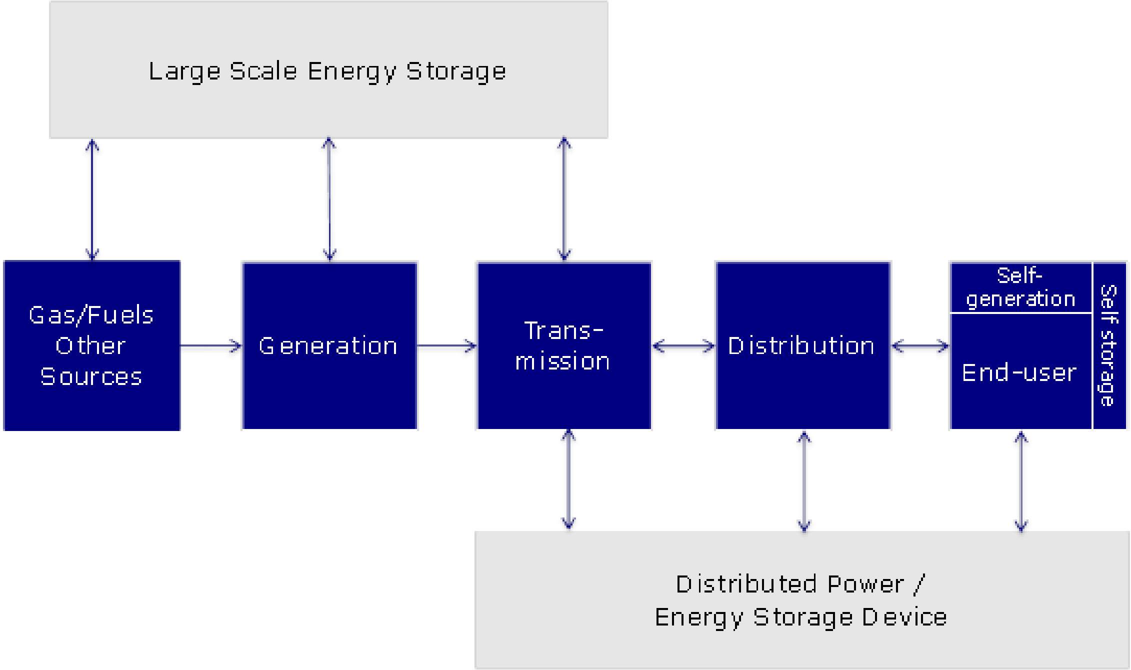
- The Connected Scenario saves € 33 bn. per year in system cost for the complete system in scope compared to the Reference Case. For the approx. 1.110 TWh of annual power exchange between MENA and Europe, this amounts to approx. 30 €/MWh.
- MENA acquires an export industry for renewable electricity worth up to € 63 bn. p.a. – more than all of the current exports of Egypt and Morocco combined.
- The marginal cost of carbon emission reductions in the power sector drops by 40% from 192 €/tonne in the Reference Scenario to 113 €/tonne in the Connected Scenario.

Power system integration can thus play a major role in creating a robust and cost effective pathway towards decarbonization. This lower cost of carbon emission reduction is achieved through an optimized mix of RES technologies, whereby power from the sun and wind is produced in the most favorable locations throughout EUMENA. The study shows that a larger system offers more options to balance the load and the output of Solar and Wind power plants. Fewer gas peakers for balancing need to be built and less excess production by RES, i.e. curtailment, occurs.

4.4 Electricity Storage

A major advantage of electricity storage is that it can offer flexibility on the supply and demand side. The operation of storage is based on fluctuations in the electricity supply and demand. In general, storage operators purchase electricity during periods of high RES feed-in and sell it during times of high demand. Energy storage can be applied to all steps of the energy value chain which is shown in Figure 14. Energy storage is used to bridge temporal, and in case of gas storage, geographical gaps between the supply and demand side. By bridging these gaps, energy storage can contribute to realising more integrated, optimised and flexible energy systems (see Ugarte et al. (2015)).

Figure 14 Energy storage in the energy value chain (source: Ugarte et al. (2015), adapted from Makansi (2008))



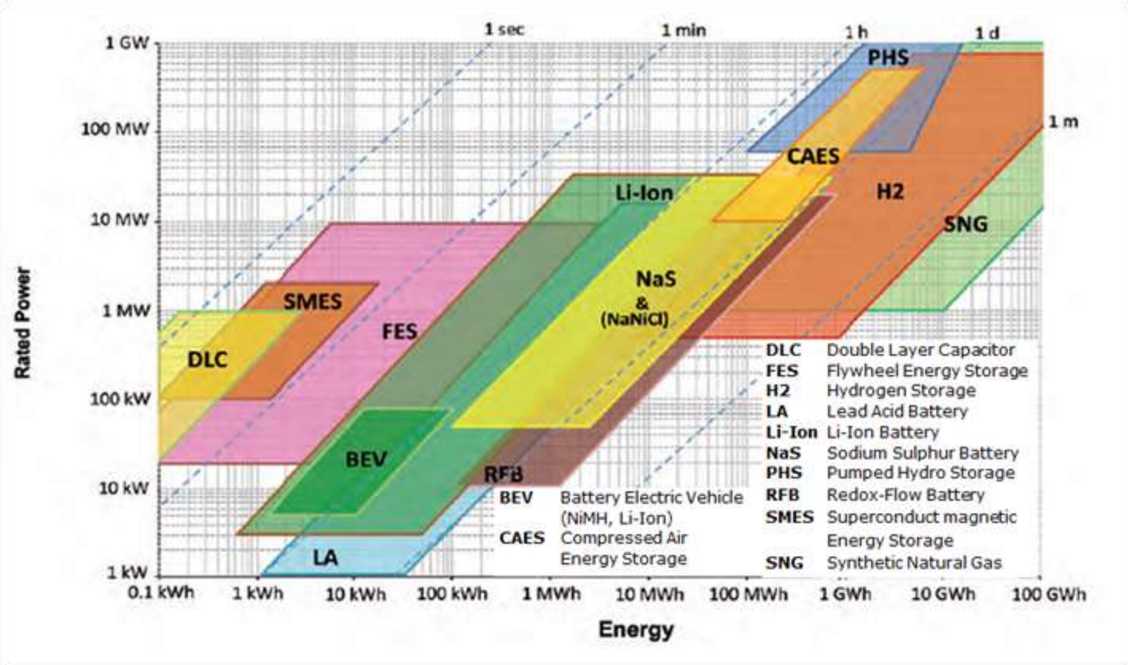
4.4.1 Classification of storage types

A broad range of storage technologies that can be differentiated with regard to the following characteristics is in place:

Large scale vs. small scale storage: Large scale storage is mainly used by energy suppliers that use it e.g. for arbitrage or for optimising the operation of their power plant portfolio. Exemplary applications for small storage are the optimisation of own consumption at household level, uninterruptible power supply or the use in mobile applications like electric vehicles.

Long term vs. short term storage: Technologies can be classified by energy and power characteristics. Some technologies like batteries have a limited storage capacity and a smaller power input, but they are very efficient and often used on a decentralised level. Others like pumped hydro or hydrogen storage can store huge amounts of energy for weeks or even months and show thus a long shifting period, but these storage types often have higher losses (see Ugarte et al. (2015)). Figure 15 illustrates an overview of the classification of storage types.

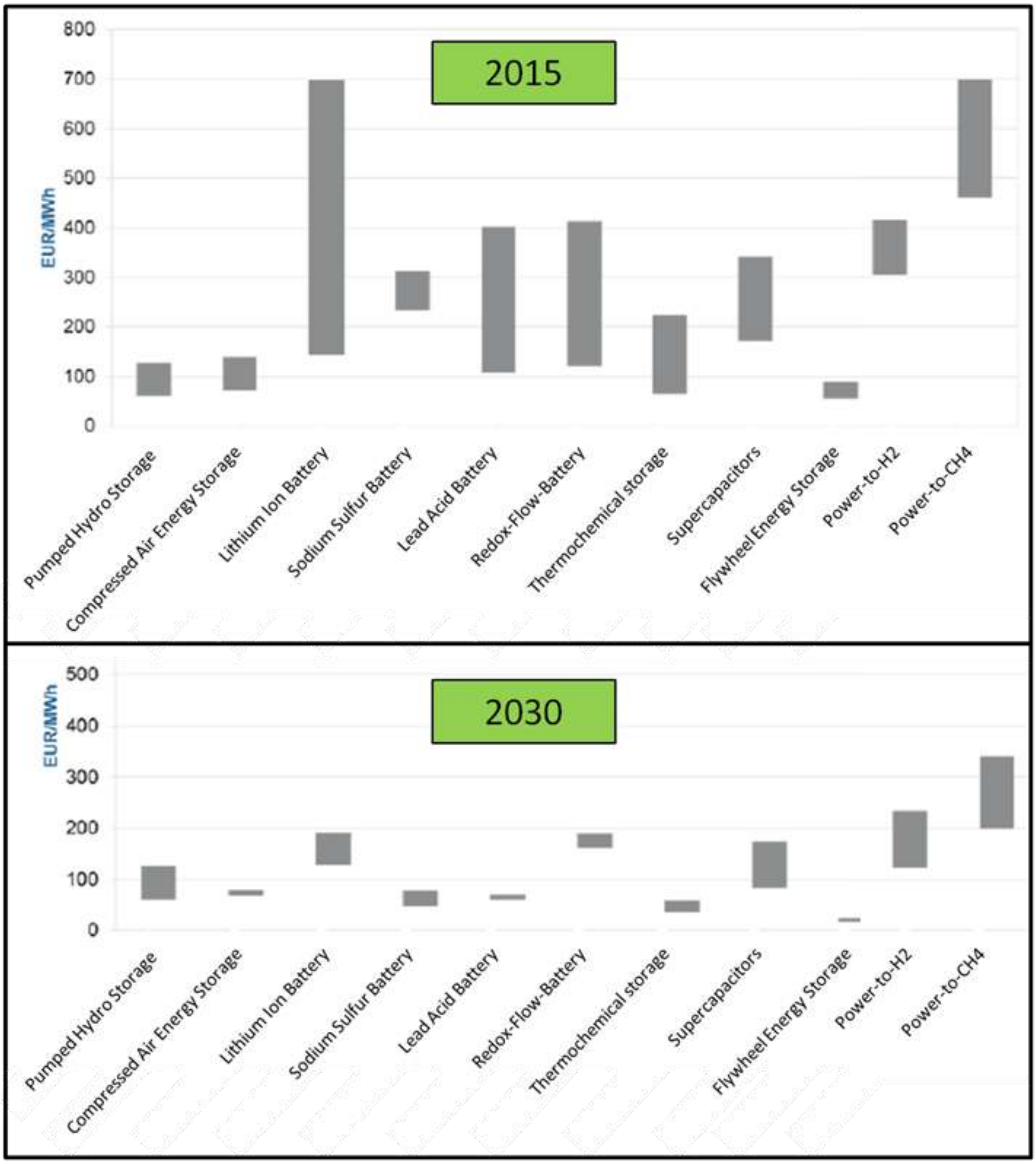
Figure 15 Comparison of rated power, energy content and charge/discharge time for different storage technologies (source: IEC (2012))



Technical and economic criteria of storage systems differ considerably. Compared to worldwide developments, in Europe, electrochemical and thermal storage technologies are currently becoming increasingly important. Thermal storage (e.g. molten salts) is growing due to the connection to Concentrated Solar Power (CSP) plants, particularly in Spain. Furthermore, the decentralisation of the electricity supply causes a need for small-scale storage systems like batteries mainly used for smaller applications that need a short reaction time. Lithium-Ion and Redox-Flow Batteries record a particular growth in installed capacities as they have a high potential for technology improvement and cost reduction (see Ugarte et al. (2015)).

Figure 16 gives an overview of the levelised cost of energy storage for different storage technologies in 2015 and 2030. For every technology, an individual and suitable application process is used and the technical restraints are considered. For the details see World Energy Council (2016). The technologies with the greatest uncertainties with regard to today's costs are most of the batteries and the Power-to-CH4 technology. This large uncertainty is illustrated by the length of the bar on the chart, and is mainly a reflection of the uncertainty in the maturity of these technologies. At present, pumped hydro, thermochemical and flywheel energy storage show the lowest cost for energy storage. However in 2030 other battery technologies reach a comparable cost to these technologies e.g. sodium sulfur and lead acid batteries. All technologies show a reduction in costs, which could be expected to have a significant impact on the total amount of storage deployed by 2030. The more mature technologies such as pumped hydro storage show a less significant cost reduction than less mature technologies.

Figure 16 Levelised cost of energy storage (source: World Energy Council (2016))



4.4.2 Need for and services of energy storage

The presented technologies serve a variety of services, so the choice of the most appropriate storage type depends on the structure of the energy system and the specific operation concept. In centralised systems, large-scale energy storage makes sense for balancing the feed-in e.g. by large wind offshore parks that are located at the coast. However a strongly decentralised system with widely distributed RES plants requires flexibility options like battery storage on a local level. Thus, the need for storage depends always on country specific or regional framework conditions. Furthermore, electric vehicles can also provide decentralised storage services if an information and communication infrastructure is built up that allows the control of vehicle charging and discharging.

The mutual influence of grid expansion and storage is exemplary shown within the DESERTEC project. Scenarios were calculated that analysed the optimal generation mix of the EU and MENA region if these regions were strongly connected or strictly separated. Both scenarios are optimized for minimum system costs and assume a growing share of RES. Interestingly, in both scenarios no storage is built beyond the existing hydro storage that is already available or in concrete and advanced development or under consideration today. The cost optimisation reveals that the use of gas turbines or the expansion of grid capacities is a more cost-effective solution than the investment in storage technologies. A sensitivity that assumes very low battery costs of 500 €/kW leads to a replacement of gas turbines and combined cycle gas turbines by batteries that enable greater Utility PV production. For more details, see Zickfeld (2012).

However, these analyses mainly focus on the use of energy storage for balancing supply and demand on a centralised level. But energy storage can provide more services, e.g. grid frequency regulation and grid stability and batteries can also handle ramping requirements, reactive power management for voltage control and the short circuit capability of the grid. The following list shows a classification of services that can be provided by energy storage and that could improve the cost efficiency of storage business models. According to Ugarte et al. (2015), five types of storage services can be distinguished:

- ***Bulk energy services*** are provided by operators of central, large-scale and often long-term storage types that help to stabilize the whole energy system. Bulk gas storage is used to increase the security of gas supply and electricity storage is often used for price arbitrage and for balancing supply and demand at a central level.
- The ***integration of RES*** is supported by storage types both at the centralised and also at the decentralised level. In this use case, storage is combined with RES plants and balances the intermittency of the power output and thus causes a more constant feed-in of RES.
- Storage systems that have a short reaction time are well suited to providing ***ancillary services***. These services contain frequency regulation, load following, voltage support in the transmission and distribution systems, black start, spinning reserve, and non-spinning reserve.
- As an alternative to grid expansion, energy storage can be used to ***relieve temporary congestions in the network*** and thereby limits the need for in-

vestments in grid strengthening. In this case, storage is applied in a way that network congestions and overload situations at substations are avoided.

- Business models for small scale storage focus increasingly on ***managing customer energy services***. They include different use cases, e.g. shifting demand and reducing peak demand especially for industrial customers, optimizing own consumption and commercialising RES feed-in for owners of RES plants or ensuring a more reliable power supply for off-grid customers. In the future, charging control of electric vehicles could be a further application within this field.

4.5 Demand Side Management (DSM)

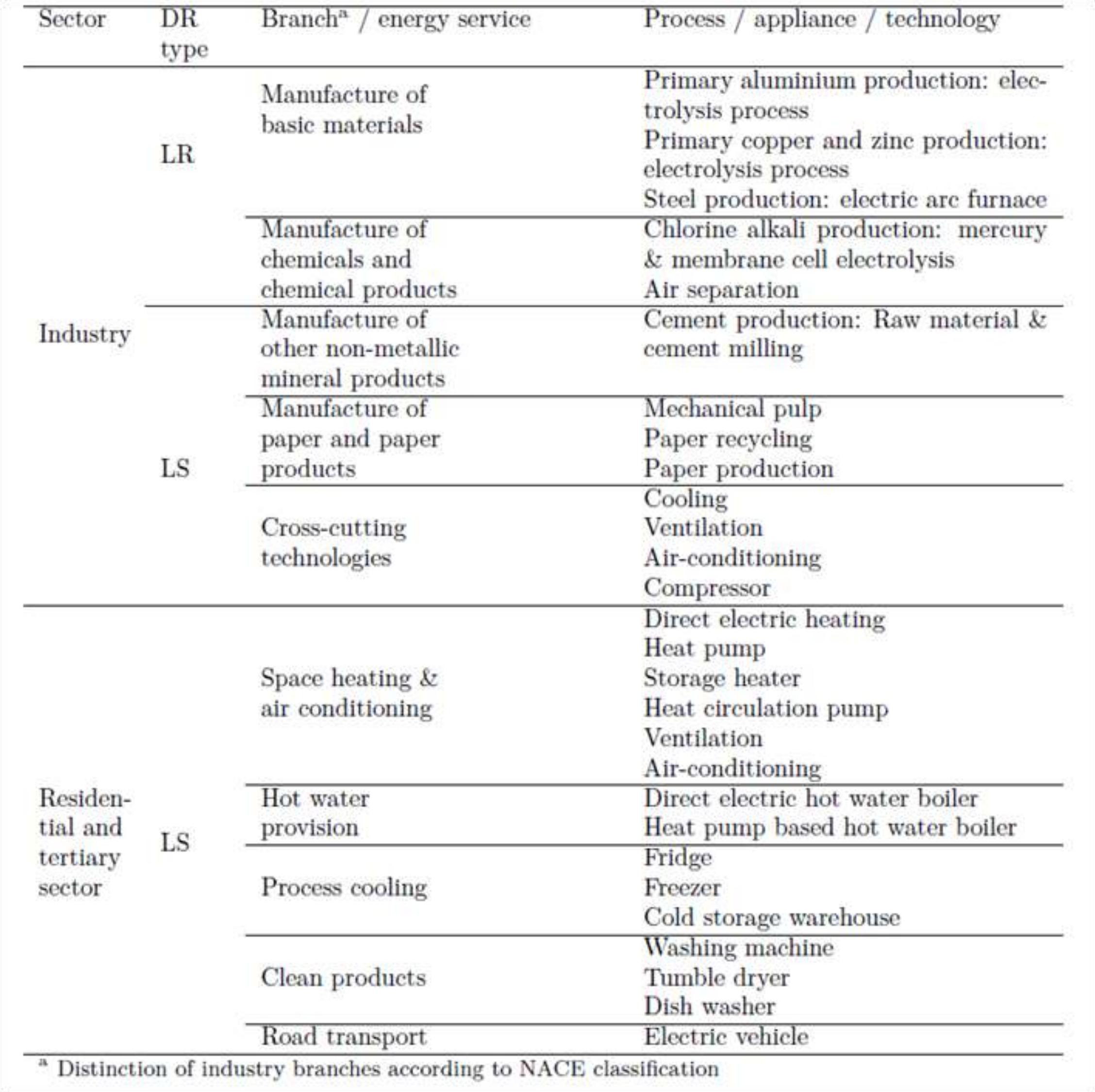
DSM offers incentives to shift the times of peak demand to situations with high feed-in by renewable energy sources. In this section, the flexibility potential of DSM of applications will be discussed for different sectors and some DSM concepts that vary with regard to the type of incentive will be presented.

4.5.1 DSM potential of different sectors

In general, DSM can be offered by flexible demand processes of different electricity consumers. A common classification of relevant processes is aligned to the industrial, residential and tertiary sector, see *Table 4*. The shift of industrial demand depends on the specific processes. Some applications like electrolysis, cement and paper mills and electric arc furnaces show a potential to shift energy requirements of the process in time. However, it must be ensured that the products' quality does not deteriorate. The costs depend mainly on personnel costs and investment in communication devices, control equipment and on-site storage if needed. In the residential and tertiary sector, DSM can especially shift the demand for heating and cooling. Furthermore, the timing of air conditioning or clean products offer a flexibility potential. Even if DSM potentials are high, the challenges lie within the building of an IT and communication infrastructure, the public acceptance and the financial incentives (see Boßmann (2015)).

Besides the existing consumers, new electricity based applications like electric cars offer a future potential for DSM. The controlled charging of electric cars is well suited for DSM because the cars are expected to consume a huge amount of electricity during the evening and night hours. Besides charging, vehicle-to-grid could be implemented, so batteries for electric cars could be discharged and feed electricity back into the grid during hours when electricity supply is needed. The potential role of electric vehicles as a DSM option depends mainly on the market success of these cars, financial incentives and consumers' acceptance (see Papaefthymiou et al. (2014)).

Table 4 classification of DSM Processes (DR – Demand Response, LR – load reduction, LS – load shift) (source: Boßmann (2015))



Sector	DR type	Branch[a] / energy service	Process / appliance / technology
Industry	LR	Manufacture of basic materials	Primary aluminium production: electrolysis process Primary copper and zinc production: electrolysis process Steel production: electric arc furnace
		Manufacture of chemicals and chemical products	Chlorine alkali production: mercury & membrane cell electrolysis Air separation
	LS	Manufacture of other non-metallic mineral products	Cement production: Raw material & cement milling
		Manufacture of paper and paper products	Mechanical pulp Paper recycling Paper production
		Cross-cutting technologies	Cooling Ventilation Air-conditioning Compressor
Residential and tertiary sector	LS	Space heating & air conditioning	Direct electric heating Heat pump Storage heater Heat circulation pump Ventilation Air-conditioning
		Hot water provision	Direct electric hot water boiler Heat pump based hot water boiler
		Process cooling	Fridge Freezer Cold storage warehouse
		Clean products	Washing machine Tumble dryer Dish washer
		Road transport	Electric vehicle

[a] Distinction of industry branches according to NACE classification

Table 5 gives an overview of technical characteristics of DSM applications. It illustrates that most applications can be controlled very fast but differ with regard to the period of shifting. Flexible Power-to-Gas and Power-to-Heat processes are included for DSM because in future energy systems with high RES shares, they could be used for electricity consumption if an oversupply of electricity occurs. Power-to-Gas means that electricity is converted into hydrogen or methane and stored or fed into the gas infrastructure. The process is very flexible, but today investment costs are very high. Power-to-Heat is less expensive and is highly efficient if heat pumps are used. However, heat production makes only sense if heat is needed in a specific situation or the heat has to be stored.

Table 5 Overview on DSM applications (source: Papaefthymiou et al. (2014))

Criteria		Industry	Residential and tertiary sector	Electric vehicles	Power-to-Gas	Power-to-Heat
Efficiency	%	95 - 100	95 - 100	93	60-80	100-300
Reaction time	%/min	20 - 100	100	100	100	100
Maximum period of shifting	hours	1 - 24	1 – 24	single car: few hours	weeks to months	up to 24 hours
Investment	-	depends, can be low	Approx. 400 € for meter, gateway and installation	-	More than 2.000 €/kw	530 – 2.560 €/kW for heat pumps
Maturity of technology	-	some customers provide already interruptible loads	low experience	low experience	high experience with electrolysis	high
Barriers	-	missing financial incentives; quality losses of products	concerns about data security; missing financial incentives, tariffs and communication infrastructure	missing business models, few vehicles today	high costs, R&D still needed	too high electricity costs

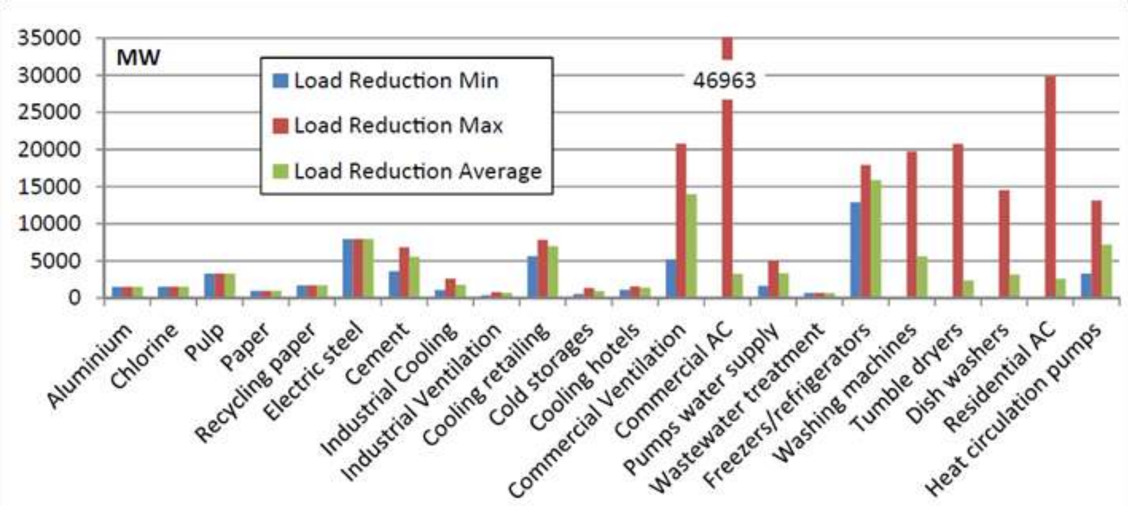
4.5.2 DSM potential

The availability of most DSM applications strongly depends on the time of day, outdoor temperature or season. In addition, the duration of interfere and the shifting time are limited, so the full potential is not available at any time. For estimations on country level, it is difficult to gather and consider all the data that is necessary to assess the realistic DSM potential. But often, it is possible to describe the theoretical potential that gives an indication of what are the most relevant sectors or applications for DSM. It comprises all facilities and devices of the consumers that are suitable for DSM irrespective of the existence of information and communication infrastructure or cost aspects.

A study by Gils (2014) gives an overview on the theoretical DSM potential in Europe. Two key results can be summarized:

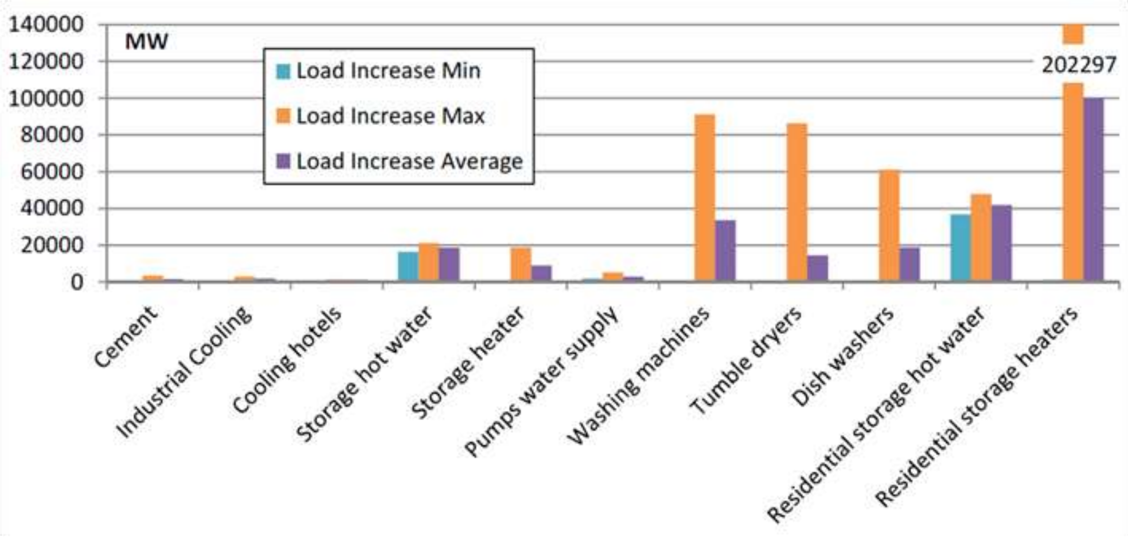
1. For **load reduction** the highest potential can be found in pulp and paper, steel and cement industry, as well as in commercial ventilation and refrigerators/freezers in retailing and private households, see *Figure 17*.

Figure 17 Potential for load reduction by consumer in Europe (source: Gils (2014))



2. For **load increase**, the potential relates almost completely to electric space heating, storage water boilers and washing equipment, see *Figure 18*. In the industrial and tertiary sector technical restrictions impede advancing loads, thus there is higher potential for load reduction than for load increase.

Figure 18 Potential for load increase by consumer in Europe (source: Gils (2014))

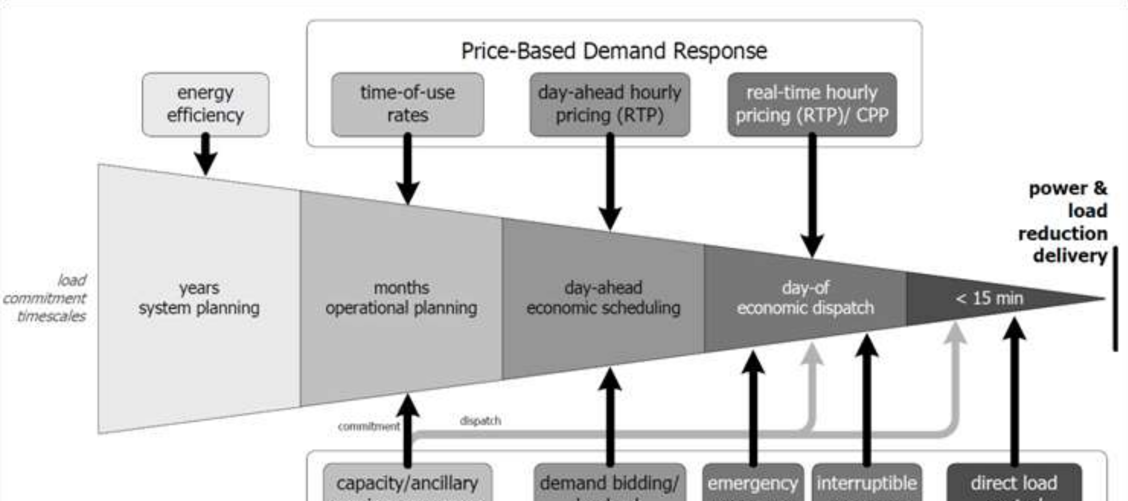


Further results that show the country specific DSM potential reveal that the industry is the sector with the highest potential in the MENA region. The tertiary and household sectors have approximately the same potential, see Gils (2014). However, especially in the MENA region, the electricity use is likely to be reduced in the coming decades in the framework of energy efficiency efforts and thus diminishes the DSM potential. But in the transition period, existing units can deliver an important contribution to DSM programs and even if future processes need less efficiency, they also could become more flexible and easier to control.

4.5.3 DSM incentive concepts

The incentive for consumers to participate in DSM measures lies within saving costs or generating profits. Automatization plays an important role in activating DSM potentials because consumers are probably not willing to manage their demand independently, so this must be realized by automatic calls of a control unit. DSM options can be deployed at different timescales of electricity system scheduling and can be controlled via price- or incentive-based mechanisms, see Figure 19. Price-based management use price variances to stimulate or mitigate consumers' electricity demand. This procedure leaves some uncertainty as the intensity of the demand adjustment cannot be predicted exactly. In the case of incentive-based measures, consumers commit themselves to adapting their individual load on demand and receive a pre-assigned payment as compensation. So, the calculability and controllability is higher in this concept.

Figure 19 Price- and Incentive-based DSM approaches (source: US Department of Energy (2006))



The price-based DSM measures use a price signal that varies over time. The following price formation mechanisms can be distinguished (see US Department of Energy (2006)):

- **Time-of-use**: The prices vary within time blocks e.g. day and night tariffs.
- **Real-time-pricing**: The prices are fixed with an hourly resolution and consumers will be informed one day or one hour in advance.

- **Critical peak pricing**: In general, this is the same mechanism as time-of-use pricing, but in critical load situations, the price is replaced by a much higher critical peak price.

Incentive-based mechanisms are classified as follows (see US Department of Energy (2006)):

- **Capacity/Ancillary Services Programs**: Consumers sell options for load reduction in advance which an administrator can use if needed. Consumers receive a payment for the provision and have to provide the required load reduction within a short time, e.g. an hour or sooner.
- **Demand Bidding/Buyback Programs**: Load shifts are planned one day in advance and the bonus is determined as a function of the electricity price at the electricity exchange.
- **Emergency Programs**: The amount of the payment is derived from real-time pricing, costs for production downtime or the value of electricity supply at that moment.
- **Interruptible/curtailable Programs**: Consumers have to pay lower electricity costs if they reduce their demand independently.
- **Direct load control**: An administrator has direct access on the control of consumers' loads and can turn them off spontaneously. Consumers are financially rewarded.

5 Market design as an important non-technical flexibility “enabler

We focus in this chapter on market design as the most important non-technical flexibility “enabler. The section gives an overview of market designs that promote the expansion of RES. On the one hand, the political decision-makers affect the expansion directly and the mix of RES by the choice of a specific support scheme. This in turn causes the flexibility need. On the other hand, market design can have an influence on the intensity of investment in flexible technologies as it can set incentives or facilitate the market entry for flexibility options. Both, RES support schemes and market design options for flexible energy systems are discussed in the following.

5.1 Support schemes for RES

The main reason for growing flexibility need lies within the rising share of RES. Among others, the needed amount of flexibility depends on the mix of RES technologies within a country. The geographical and climate conditions determine which mix of RES plants will be built. Besides, the support schemes influence the mix of RES plants within the market area because they can set financial incentives for investing in specific RES types. Therefore, a short overview of different support schemes is given, following IRENA and CEM (2015).

Tariff-based instruments provide economic incentives for electricity generation by RES, awarded in the form of investment subsidies or as a payment for the energy generated. Examples include feed-in tariffs (FIT: fixed price for the remuneration of renewable energy fed into the grid) and feed-in premiums (FIP: payment to renewable energy generation on top of the electricity market price).

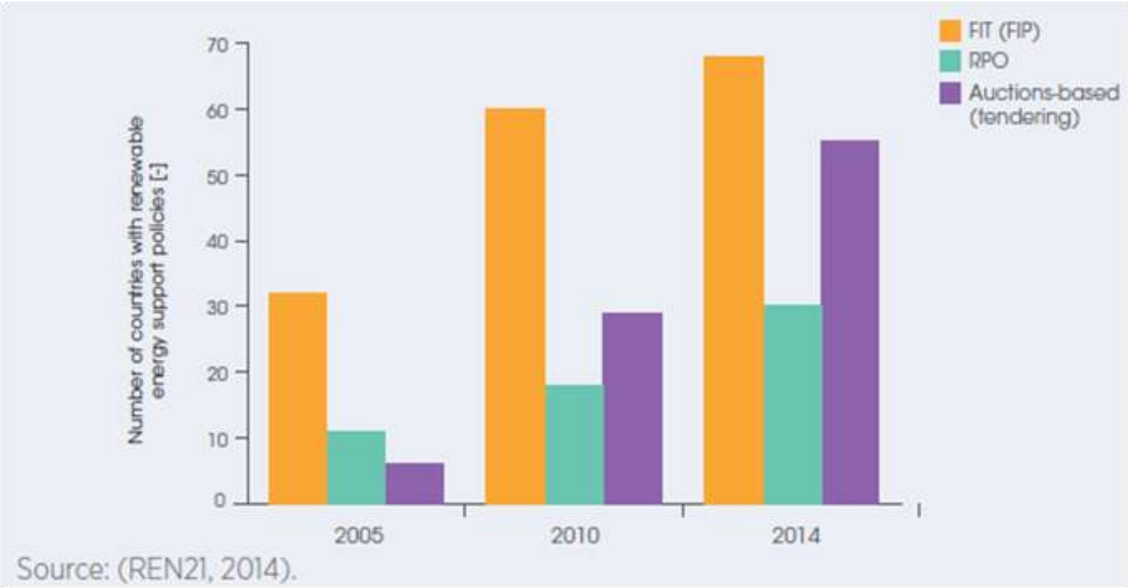
Quantity-based instruments provide direct control over the amount of renewable capacity installed or energy produced. A renewable purchase obligation (RPO) is such an instrument, imposing a minimum quota or a share of renewable energy production on electricity suppliers, and is often supplemented by a renewable energy market allowing for the trading of renewable energy certificates. Compared to tariff-based instruments, quantity-based mechanisms offer better guarantees that the target will be met, but they provide less assurance to project developers with respect to future cash flow, because the latter bear the financial risk.

Hybrid instruments combine features of tariff- and quantity-based instruments. In auction-based mechanisms, both price and quantity are determined in advance of realising the RES projects through a public bidding process. By this, auctions can be more effective than pure tariff or quantity-based instruments, providing stable revenue guarantees for project developers (similar to the FIT mechanism), while at the same time ensuring that the renewable generation target will be met (similar to an RPO). The bidding process allows the determination of a price, and, with enough competition, the auction’s result can be cost-effective.

Figure 20 shows the development of adopted support mechanisms from 2005 to 2014. All three mechanisms have experienced growth during this time. Tariff-based instruments are in 2014 still the most common types but the strongest growth is achieved by auction-based instruments. There are some reasons for this development. The lower costs of renewable energy technologies and the relative competitiveness to other electricity producers but also the priority of goals of policy design influenced the adoptions of auctions. Countries that started early to adopt the tariff-based instruments had increasing costs, so countries that decided to implement support schemes for RES later on learned from the mistakes of the early adopters (see Elizondo-Azuela and Barroso (2011); IRENA and CEM (2015)).

Developing countries accounted for many of the new adoptions in the period from 2010 to 2014. Budget limitations and the fact that affordability of energy is a key strategic goal in many of these countries result in a preference for policies that facilitate the limitation of support costs, while stimulating deployment (see Elizondo-Azuela and Barroso (2011); IRENA and CEM (2015)). The auction mechanism has gained popularity as an instrument to support RES and was adopted by more than 60 countries by 2015.

Figure 20 Number of countries clustered by RES support instruments (source: IRENA and CEM (2015))



5.2 Market design options for a flexible energy system

The design of market regulations can favour or hinder the use of flexibility options. The following characteristics of the market design influence the flexibility potential in an energy system (see Papaefthymiou et al. (2014)).

Geographic market size: A huge energy system with an intense trade flow with neighbouring countries allows sharing and an efficient use of flexibility resources. Besides, the fluctuation of RES feed-in is lower if the geographical spread is higher and climate characteristics vary within the system's boundaries.

Market coupling: The precondition for market coupling is that neighbouring markets are well connected by grid capacity and regulations exist as a basis for cross-border trading of flexibility. Then, market coupling would mean that a common market area is created that matches supply and demand for the whole region in the most efficient way. So, the flexibility need of this common market area is typically substantially lower than the aggregated need of the two single markets.

Prequalification standards: Market actors have to fulfil specific standards if they want to participate in energy markets. These standards comprise technical characteristics like minimum sizes of bids which are advantageous in order to simplify the trading mechanisms. In order to encourage competition and the entrance of new players may e.g. the entitlement for pooling of several small units contribute.

Scheduling times: Trading of electricity is divided into defined time blocks. It is developed historically that these blocks follow the supply pattern of fossil power plants in many energy systems. As flexibility options provide flexibility in general for a shorter time frame than conventional units, shorter operating periods would facilitate bidding and market integration of these technologies. Consequently, shorter time periods could favour bids from more flexible power units and from the demand side.

Gate closure: Feed-in by photovoltaic and wind is characterized by high fluctuations and a difficult forcasting. In order create better market conditions for RES, trading rules must be adapted. If feed-in of RES has to be reported a long time in advance, the forecasts show a higher uncertainty compared to a shorter lead time. So, a gate closure that almost corresponds to real-time allows better forecasts and a smaller need for balancing reserves.

Capacity payments: Some flexibility options have small variable costs but high investment costs. This means that it could be difficult to get compensations that are high enough to cover these capital costs. Capacity payments could help to incite investment in these technologies.

Transparency: If the speed of trade activities increases because of shorter scheduling times for bids or real-time pricing, it is important to offer information to market participants very fast. Furthermore, all market participants should have the same access to important data. This ensures a fair competition, enables them to calculate their bids on the actual data basis and should lead to an efficient electricity supply.

6 Summary and Conclusions

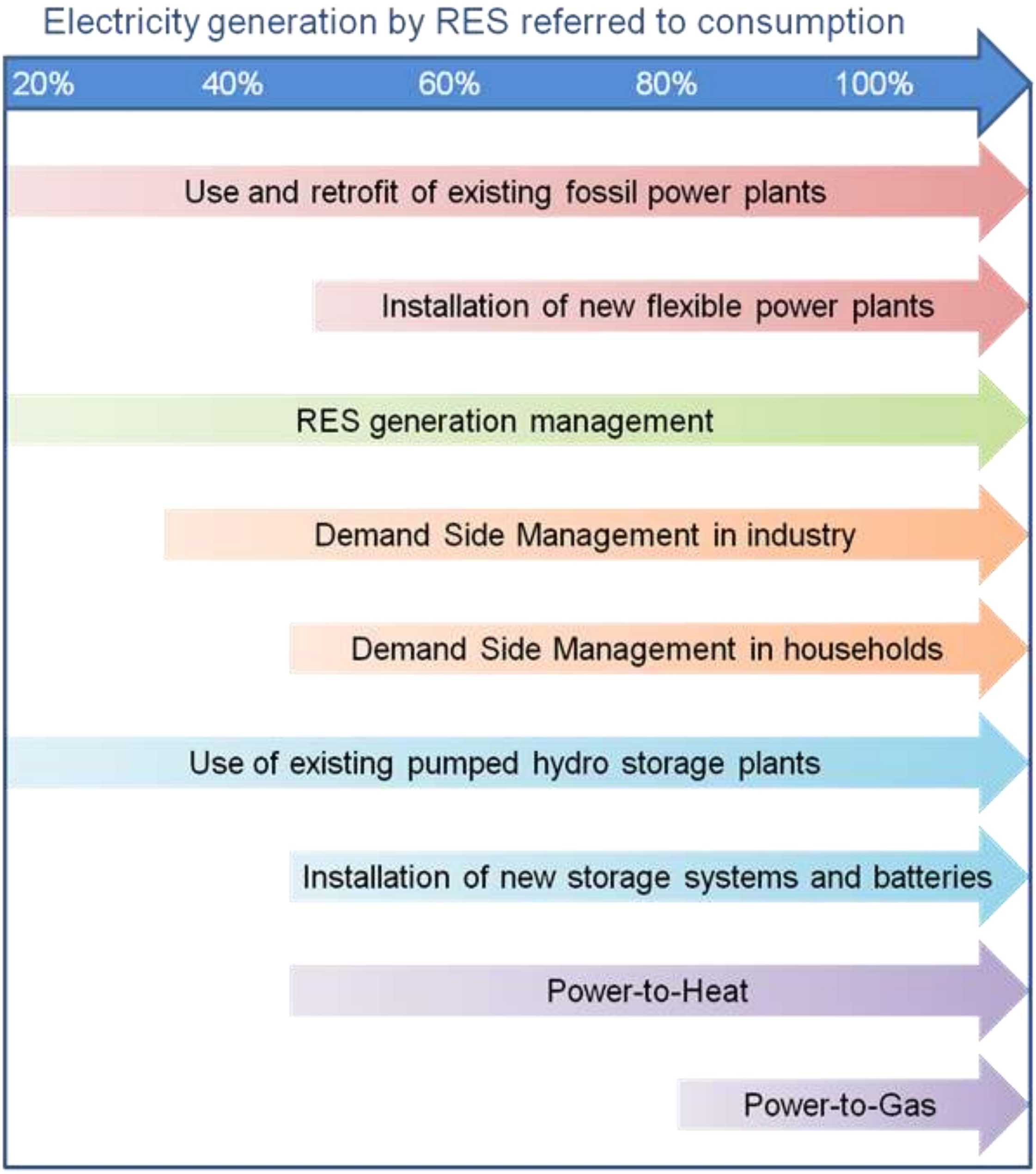
This report gives an overview of components and factors of influence that affect the increasing need for flexibility in energy systems with growing shares of renewable energy sources (RES). Different flexibility options are presented and discussed. In this context, flexibility was defined as the ability of a power system to balance variations of supply and demand and to guarantee security of supply and system stability. It becomes clear that the need for flexibility results mainly from the fluctuating character of power feed-in by wind and photovoltaic plants. However, the flexibility need of countries differs with regard to these factors: atmospheric conditions, geographic location, grid connection to neighbouring countries, mix and regional distribution of RES plants. By consequence, the flexibility need can vary amongst countries.

Various flexibility options exist that can be used for balancing supply and demand. They differ with regard to their technical and economic characteristics. Some options such as control of RES and fossil power generation or the use of batteries show short reaction times and allow a quick adaption to the specific situation. Other technologies like long term storage can be used to bridge long time spans with RES feed-in downturns. As there will be different challenging situations in the future energy systems, also diverse flexibility options will be needed to respond to these situations. It can therefore be concluded that a mix of technologies and concepts will be used in the future to respond to the flexibility demand which will vary over different energy systems and RES penetration rates.

In an early stage of RES deployment, operation management of fossil power plants, power control of RES, intense use of existing storage and grid expansion will be applied. Through this, additional investment is avoided at an early stage of RES expansion and the existing flexibility potential is exploited before new technologies or services are used. With always increasing shares of RES in the system, Demand Side Management, new flexible power plants and additional storage systems could become necessary amongst others (see *Figure 21*). The order of flexibility options follows technical and economical criteria, e.g. efficiency and costs of the flexibility provision. So, applications that show little losses and considerable low costs like Demand Side Management are used at an earlier stage than Power-to-Gas which has high conversion losses and high costs.

However, new flexibility options are needed with increasing RES shares and new business models will be required that stimulate investments in new flexible technologies and services. Since there is a certain dynamic in the development of flexibility options a flexible market design that rather tenders for service levels than technologies may be the most adaptive response to this challenge.

Figure 21 Use of flexibility options in dependence of the RES share within an energy system (source: Krzikalla et al. (2013))



The need for investments into flexibility maybe substantially reduced by cross-border cooperation, since the balancing effect in a large market is frequently a very cost efficient means to improve the robustness of the grid. A harmonised energy policy could further reduce the need for a rather cost-intensive expansion of flexibility options.

In order to activate the power of the market for the benefit of the system, the market design should also ensure non-discriminatory access to the energy market for all flexibility options. A complementary framework that sets adequate incentives for investments in flexibility options may consider strategic preferences but also improve investment security. RES support schemes should be developed in a way that they grant a cost-effective expansion of RES and also consider the consequences of the RES build-up for the flexibility need that could mean additional costs. Thus, the build up of RES plants should be accompanied by a strategy that ensures that enough flexibility is provided for balancing the energy system and maintain system stability.

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Annex 1

The fluctuating feed-in of renewable energy sources is the main reason for the need for flexibility. This chapter presents different RES technologies and their economic characteristics. Furthermore, the contribution of RES to the provision of flexibility is discussed.

Overview of installed and planned RES capacities worldwide

The installation of RES plants is increasing worldwide. RES were the second-largest source of electricity in 2014 behind coal (see IEA (2015)). A capacity of 147 GW RES plants was installed in 2015, so the global capacity is estimated at 1.849 GW whereof 1.064 GW account for hydropower. This means that RES covered an estimated amount of 29 % of the world's power generation capacity at the end of 2015 and could have covered approximately 24 % of the global electricity demand. Wind and photovoltaic together made up about 77 % of all RES capacity built in 2015 (see REN21 (2016)). Figure 22 illustrates that the share of RES technologies that is used for electricity generation differs much not only today but also in the future (according to the IEA New Policies scenario, see see IEA (2015)). Figure 23 shows the distribution of RES technologies across the world and selected countries. In some countries, a high potential of RES combined with a comparable low electricity demand lead to RES shares above 60 %. However, in many industrialized nations that have high energy consumption, RES shares lie below 30 %.

Figure 22 Development of RES technologies according to the IEA New Policies Scenario (source: see IEA (2015))

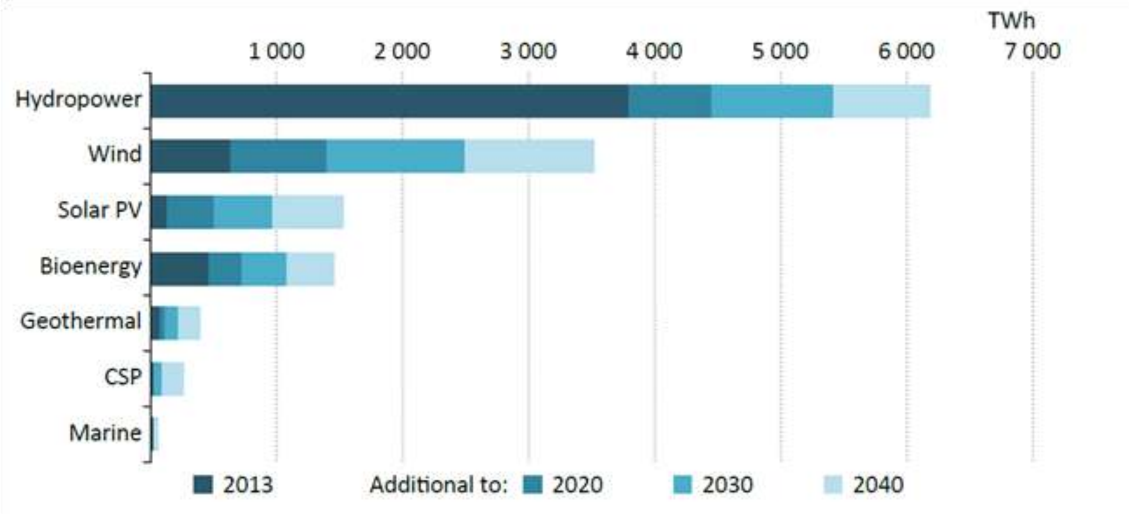
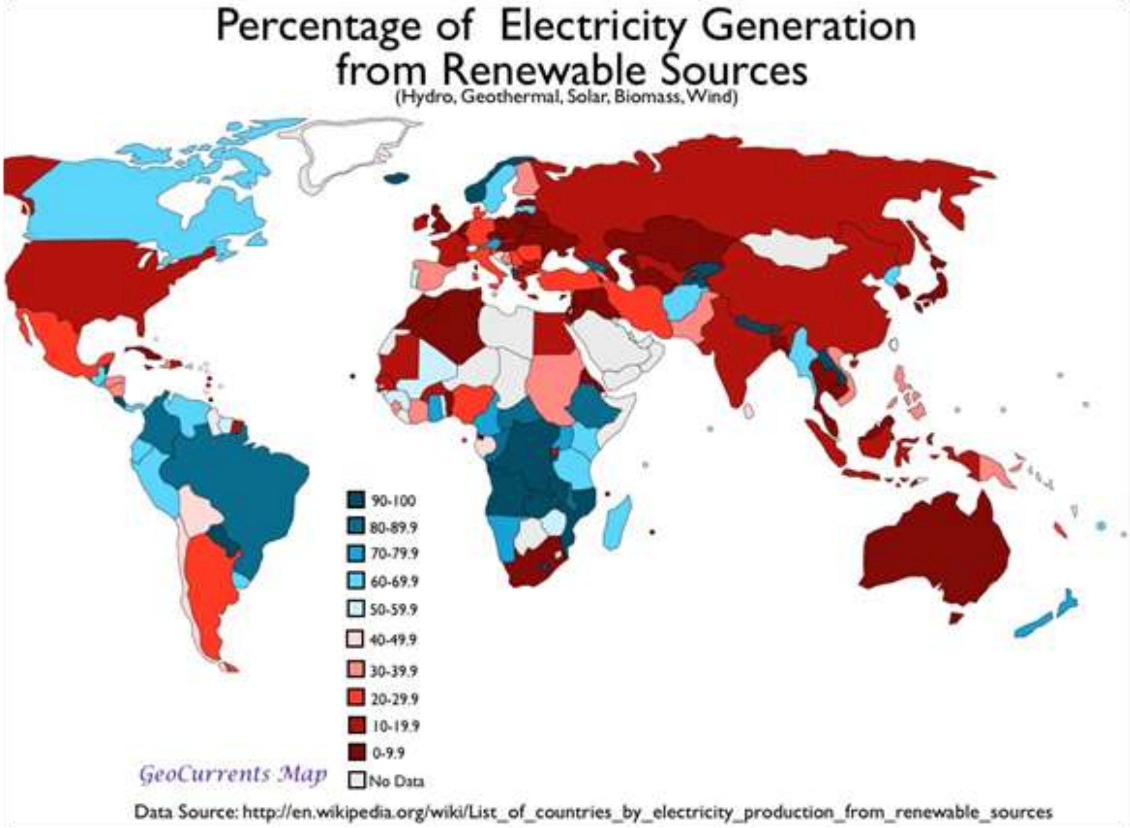
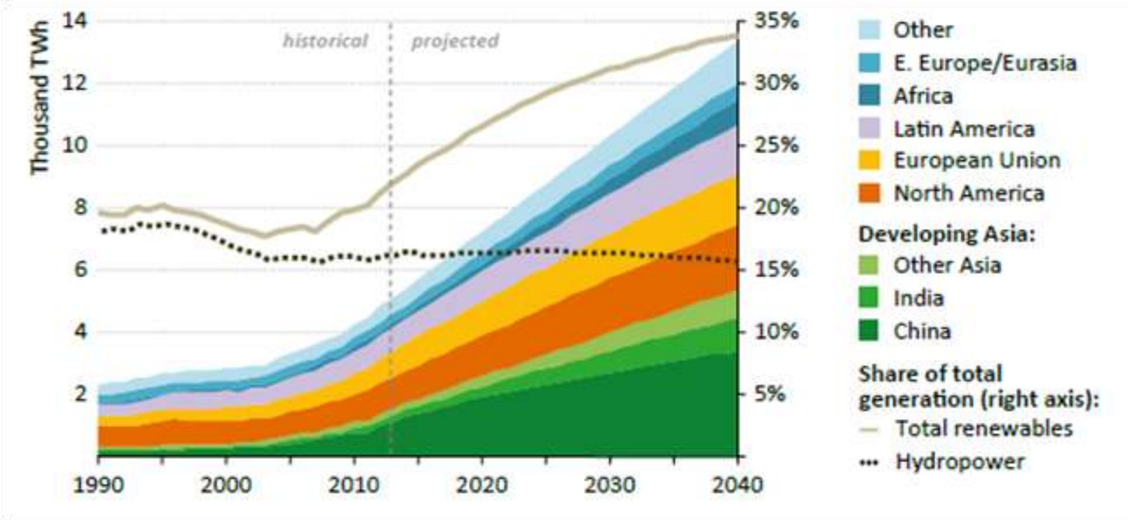


Figure 23 Share of RES corresponding to the electricity generation within countries (source: GeoCurrents (2012))



The reasons for the current success of RES lie within lower costs especially for wind and photovoltaic because of technological advances, expansion into new markets with better resources and improved financing conditions caused by ubiquitous low interest rates as much as improved confidence of banks into these technologies. In favourable circumstances, RES are cost-competitive with fossil power plants, e.g. wind power was most cost-effective in many countries in 2015, including Brazil, Canada, Mexico, South Africa and some more. Morocco was the world’s largest market for Concentrated Solar Power (CSP) in 2015 (see REN21 (2016)). It is expected that the share of RES will grow in the future, especially driven by a lot of potential in Asian countries as it is shown in Figure 24. For a detailed description of the RES developments in different regions see also: REN21 (2016).

Figure 24 Development of electricity by RES according to the IEA New Policies Scenario (source: see IEA (2015))



The transformation of the energy system can mean that a centralised supply system is replaced by a more complex system with many decentralised generating assets. A key challenge is the integration of RES feed-in e.g. by adapting the power grid and developing more flexible systems that are able to balance variable resources at reasonable costs. However, it is also possible to build up a centralised RES supply e.g. wit CSP or wind offshore plants. In this case, grid connections are needed that link these plants with regions of high demand. But, in general, it means a transformation process for the countries that decide to increase their RES shares. Policy makers should be aware that this process has undeniable consequences for the whole economic sector.

Economical performance of different RES types

RES show different feed-in patterns that are influenced by a variety of factors. Feed-in of wind and photovoltaic plants depend mainly on wind and solar radiation which causes a very fluctuating feed-in pattern for wind and a variable but more regular day-and-night-pattern for photovoltaic. Hydropower has an approximately constant power generation if no seasonal water scarcity occurs and the electricity output of biogas plants can be controlled if a biogas storage system exists.

The weather conditions do not only affect the hourly feed-in patterns of wind and photovoltaic plants but also their full load hours and thus their cost-effectiveness. Therefore, the selection of the location is crucial for the output of RES plants and southern countries with high solar radiation focus on photovoltaic installations whereas windy locations can be found often at the coast. Therefore, a global comparison of electricity generation costs is not as easy as for fossil power plants, because the local weather potential has to be included in the calculation. Figure 25 and Figure 26give an overview of regional investment costs of different power plants and the resulting costs of electricity. It becomes clear that there are broad cost ranges for a single technology even in one region as the output of a RES plant depends on the geographical conditions. In all regions, hydro, wind onshore and photovoltaic show relatively low installed costs. With regard to electricity costs, especially biomass, hydro, geothermal and wind onshore plants are in most regions able to compete with fossil fuels.

Figure 25 Total installed costs of utility-scale RES technologies by region in 2013/14 (source: IRENA (2015))

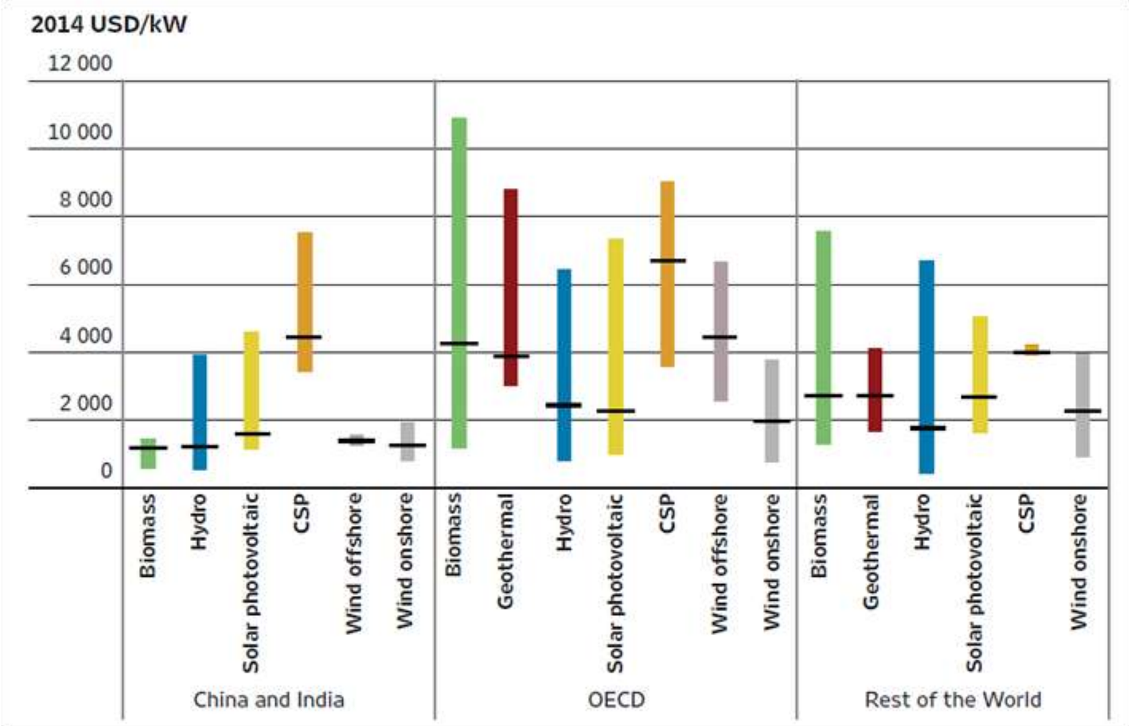


Figure 26 Cost of electricity by region for utility-scale RES 2013/14 compared to fossil power plants (source: IRENA (2015))