REflex

Analysis of the European energy system

Policy Brief

Flexibility options in the context of future energy systems – some scenario-based reflections

Witold-Roger Poganietz
KIT ITAS

André Kühn
Fraunhofer ISI

Ulrich Reiter
TEP

Francesca Fermi
TRT

Bibliographical data

Witold-Roger Poganietz
Karlsruhe Institute of Technology (KIT),
Institute for Technology Assessment and Systems Analysis (ITAS)

André Kühn
Fraunhofer-Gesellschaft, Fraunhofer Institute for Systems and Innovation Research (ISI)

Ulrich Reiter
TEP Energy GmbH

Ulrich Reiter
TEP Energy GmbH

Francesca Fermi
TRT Trasporti e Territoro srl

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CCS	Carbon Capture and Storage	HV	High voltage
CO_2	Carbon dioxide	HVDC	High voltage direct current
CSP	Concentrated Solar Power	MS	Member States
DSM	Demand side management	PV	Photo voltaic
EV	Electric Vehicle	RES	Renewable Energy Sources
GHG	Greenhouse Gas		

1 Introduction

In the European Union a common understanding still exists that a future European energy system shall contribute to the EU climate policy aims. This understanding extends the aims of energy policy: To de-carbonize energy-induced emissions is added to the traditional ones, like secure and affordable energy supply (cf. Hildingsson et al. 2012).

Defining an additional aim sets only a broad frame for the design of the future energy system. This leaves many options open regarding the future shape of the energy system. In principle, looking e.g. at electricity, technical feasible combinations of technologies are manifold allowing for e.g. renewable energy sources (RES) with nuclear power plants as well as coal power plants combined with carbon capture and storage (CCS) technologies. However, according to the Energy Roadmap of the European Commission, renewables are seen as the corner stone of any future energy system (COM 2011/0112). In case of electricity this favours mainly wind and solar energy which are known for their intermittent nature, with biomass and other renewable energy sources left behind. Heat production is still less dependent from intermittent energy sources compared to electricity; but this could change to some extent, as electricity to heat technologies could further deploy the market, besides the possible growing relevance of solar energy. Flexibility options on the supply and on the demand side seem to be a sine qua non for any future design of an energy system.

The most suitable combination of flexibility options is strongly interrelated with available energy supply and demand technologies. But, the interdependency between flexibility options and conversion technologies as well as demand for energy is determined not only by economic constraints but also the availability of technologies and resources.

Energy systems could be seen as socio-technical systems, i.e. technical change and societal dynamics influence each other. Due to the relevance of societal dynamic values and behavioural patterns, the degree of acceptance and willingness to support technical changes as well as social policies and regulation are equally important for the success of a transformation process, compared to technological or economic factors (Verbong and Loorbach 2012). Thus, the future design of the European energy system, and by this the most suitable mix of flexibility options, is highly dependent of over the time changing interdependencies between economic constraints, availability of technologies and resources, and societal preferences and demands. The interrelationships vary between the Member States (MS), increasing the complexity for any widely accepted solution regarding the design of the European energy system.

To deal with the complexity and the uncertainties of the transformation process, scenarios are a proven tool to structure and trigger discussions.

The aim of this Policy Brief is to sketch the relevance of the future energy system design for the significance of different flexibility options. To clarify the options, two framework scenarios will be presented which account for socio-economic and socio-political uncertainties.

2 Characterization of the scenarios

The goals of the European climate policy

The fundamental assumption regarding to the later presented scenarios is to establish an energy system fulfilling the goals set by the EU climate policy, i.e. to de-carbonize most of the emissions until 2050. According to that aim, the entire greenhouse gas (GHG) emissions shall decline until 2050 by 80%, compared to 1990, whereas the overall achievement range has been defined as -79% to -82% in 2050 compared to 1990 (COM 2011/0112). For each sector, specific targets were set (s. Table 1).

Table 1: GHG emission reduction targets for 2050, compared to 1990

Sector	Target
European Union	-79% to -82%
Electricity (CO_2)	-93% to -99%
Industry (CO_2)	-83% to -87%
Transport (incl. CO_2 aviation, excl. maritime)	-59% to -67%
Residential & Services (CO_2)	-88% to -91%
Agriculture (non CO_2)	-42% to -49%
Other non-CO_2 emissions	-70% to -78%

Note: Regarding heat no specific targets exist. They are included in the targets for the sectors Buildings & Services and Industry.
Source: COM 2011/0112

Additionally, as milestones on the way to 2050, three climate and energy policy targets for 2030 had been defined:

- reducing greenhouse gas emissions by at least 40% (compared to 1990);
- increasing the share of renewable energy sources to at least 27%;
- increasing energy efficiency by at least 27%.

Implications for the REFLEX modelling exercise

Following the Energy Roadmap of the European Commission, within REFLEX this is transformed in a share of renewables for producing electricity in 2050 of larger than 80% of total electricity production in the European Union[1].

To fulfil the greenhouse gas emission goals it is obvious that the transport sector has to experience a long-lasting increasing fuel efficiency of conventional power train technologies and de-carbonized fuels, if conventional power trains will stay the dominant technology. Electric vehicles (EV), either battery-based or fuel cells, could enter the market successfully, crowding out conventional power trains, at least for passengers cars. Improved demand management (e.g. improved public transport, car sharing) could contribute to achieve the GHG emission targets. It should be noted, that the future technology mix in the transport sector is part of the research within REFLEX. Several economic factors, like infrastructure costs, and non-economic factors, like driving profiles as well as annual mileage, will determine the mixture of power trains. The mix could differ between trucks, busses and passenger cars as well.

To achieve the emission reduction target in industry, newly developed and more efficient and alternative production technologies need to make an important contribution. In the residential sector all new buildings from 2021 onwards need to fulfil the ‘near-zero-energy buildings’ standard in accordance to the Energy performance of buildings directive (DIR 2010/31/EU). Furthermore, increasing the retrofit rate of existing buildings could be realized including more efficient components and systems, energy management etc. The energy carriers for heat production will be substituted from currently mainly conventional ones to renewables until 2050.

Societal embeddedness of the energy system transition

The continuation of the transformation process requires a general approval by the societies of the Member States. Irrespective of such a general approval establishing an energy system supporting climate policy is no “sure-fire access”. It needs an elaborated setting of legal rules, economic incentives and available technologies and resources. The targets, however, allow for different energy regimes. Furthermore, any shaping of the future energy system will affect stakeholder in different ways, and not always positively. For example, a comprehensive use of renewables is rather land demanding and requires noteworthy interventions into the landscape promoting land owner and discouraging those who see the landscape as a recreation area. Thus, an undisputed transformation process to a de-carbonized energy system cannot be expected. Various convictions regarding the most suitable design compete in political and scientific discussions, grounded on different claims and beliefs. In case of electricity these could range for example from de-centralized, semi-autonomous energy systems to rather centralized ones, with extended grid and large-scale storage systems. That means, the design of the future European energy system will be the outcome of a long-lasting social negotiation process with presumably disruptive elements.

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[1] On March 29th, 2017 the United Kingdom initiated the process of leaving the European Union. Nevertheless it is assumed, that the energy policy of the United Kingdom will follow the aims set by the European Commission within the Energy Roadmap. Therefore, it is treated as a member of the EU.

Due to the complexity of the entire energy system and due to different challenges energy sectors face, it is obvious that society has to deal with an intensive discussion regarding the future shape of the energy system.

The relevance of that discussion and, as discussed later, the significance of the shape of the energy systems design for the combination of flexibility options, calls for two different energy scenarios. In the following the first one is called “centralized world”, the second one “de-centralized world”. Both scenarios stand for two possible designs of an in the society embedded energy system. Any future energy system will be characterized by “centralized” and “de-centralized” elements. However, each scenario accentuates either the “centralized” or the “de-centralized” elements with incorporating always components of the alternative design. The precise shape of each scenario will be to some extent the result of computation. For all scenarios the assumption holds, that the overall framework in which the transformation is carried out, will not be altered by reality until 2050[2].

REFLEX Scenario I: a “centralized world”

The “centralized world” scenario describes a world, in which the electricity market will be dominated by large concentrated solar power plants (CSP), open space PV plants and off-shore and large scale on-shore wind power plants at prime locations. To realize the advantages of such system, i.e. rather low generation costs and making use of deviating loads between North and South Europe, the required grid infrastructure will integrate amongst others HVDC lines. Despite the high share of RES, the scenario would allow for some large-scale conventional, low carbon emitting power plants and nuclear power plants.

The heat production for residential and office buildings is centralized in the cities, equipped with large-scale thermal storage charged with power to heat technologies and large heat pumps. Decentral storage capacities will remain expensive and hence there will be low spill-over effects from the mobility sector (car batteries). Only basic charging infrastructure for electric vehicles will be available. Prices for EV will decline slowly. This will lead to a low EV ownership. To achieve the greenhouse gas emission targets increased fuel efficiencies and “green” fuels “have to make the job”. Otherwise additional measures will be implemented to achieve the targets.

Economies of scale will promote larger capacities of conversion technologies (as long as policy interventions will not encourage investment in small scale technologies), resulting in a more centralized world. But the costs of transporting energy will influence the degree of centralization, i.e. high transport costs could hinder the establishment of a centralized world. Having said that, a “centralized world” can be characterized by a more market-oriented paradigm, assuming in the scenario that economies of scale will dominate transport costs. The selection of the energy technologies as well as flexibility options will follow more profit-oriented rules. Current regulations, which support local, non-commercialized energy provision, are not extended. A market oriented paradigm means also a rather traditional organization of the

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[2] Within REFLEX an additional energy regime or energy scenario will be analysed: a moderate renewable scenario (aka Mod-RES). Mod-RES scenario is comparable to a business-as-usual type scenario and will be no further discussed in this Policy Brief.

energy markets, i.e. the classical dichotomy of supply and demand will apply; prosumers or non-profit-oriented energy association will not experience a noteworthy share at the electricity market.

A pre-condition for this is a generally acceptance of the required infrastructures, e.g. of HVDC lines, or intervention into nature, e.g. to establish PV plants on fallow land, in affected regions. This acceptance could be either the result of appropriate incentive systems, like the possibility to buy shares of the network operators at preferential conditions or the common understanding that the economic advantages of such centralized system outweigh the environmental disadvantages.

The establishment of such an energy system requires corresponding measures by the national governments and the European Commission, following a centralized policy scheme, e.g. directing expansion plans. Limiting appeals by citizen to speed up investment in the grid could be part of such a policy.

REFLEX Scenario II: a “de-centralized world”

In contrast to the “centralized world”, the “de-centralized world” scenario characterizes an electricity market which will be dominated by roof-mounted PV plants and on-shore wind power plants at all possible locations, amended by further local based energy technologies, like small-scale biomass power plants. A consequence should be a diminishing relevance of intra-European trade of electricity. Large conventional power plants will be rather negligible. The residential heat production is backed by building district heating systems with solar systems and small scale storage systems. Decentral storage capacities will experience lower costs, promoting better infrastructure of charging stations. This will lead to higher numbers of electric vehicles with more vehicles-to-grid.

A “de-centralized world” implies that non-efficiency oriented factors are gaining influence in the shaping of the future energy system. A main driving force for many advocates is the conviction that only grass-root movements could secure the energy transition towards RES and would impede a non-sustainable energy system (cf. e.g. Viardot et al. 2013). The local or regional energy systems (including local infrastructure) have to be owned and controlled by local groups or local residents to secure amongst other a fairer distribution of wealth by breaking up the market power of large utilities. However, the REFLEX “de-centralized world” scenario will allow for profit-oriented companies as market participants. Although in such a world, profit-orientation will not be the dominant motivation for providing energy, the operator will organize the energy system still cost-efficiently.

A “de-centralized world” could also be a consequence of a deep-rooted opposition in affected regions against new HV or HVDC-lines, which cannot be overcome by policies.

A pre-condition for a “de-centralized world” is a generally acceptance of relevant power and heat energy conversion technologies either in the neighbourhood – electricity – or in the buildings – heat. This could mean to some extent intervention into nature, e.g. to establish decentral wind power plants. This acceptance could be either the results of appropriate incentive systems, like the possibility to participate at the profits of energy sale, or by reduced tariffs.

The establishment of such an energy system requires corresponding measures by the national governments and the EU Commission. But in contrast to the “centralized world”, these measures will set only a broad legal and economic frame for establishing local groups, like local energy associations and has to be amended by regional or local directives and pushed by local groups. The transformation is more a bottom-up process.

A pre-condition for both scenarios is the switch of the current energy system to smart(er) grids, smart metering and smart appliances and thus, acceptance by the user for those technologies (cf. Verbong et al. 2013). The demands for smart systems will differ between both “worlds”, since the requirements regarding the control systems and the combination of flexibility options are influenced by the “centralization” grade of the energy system. Still rather unclear is, how the different demands will influence the user acceptance and by this, the future shape of the energy system.

Both scenarios differ in the design of the energy system but not regarding the overall framework, like population growth and economic growth[3]. But the different designs will affect some variables differently, like electricity prices. Regarding general drivers, the scenarios will make use of the latest EU Reference Scenario 2016 provided by the European Commission (Capros et al. 2016).

3 Flexibility options in the context of different energy regimes

Flexibility options in a “centralized world”

A characteristic of the “centralized world” is an intra-European trade of electricity, i.e. excess demand or excess supply in one region can be mostly, if not completely, buffered by other regions. Additionally, respective large storage systems are available for balancing the grid system. More centralized information availability on status and condition of large-scale power plants allows for better forecasting of available renewable generation (day ahead). Based on the available and precise information on generation capacity online at every time interval, the need for demand side flexibility is limited. Other central options, e.g. flexible power plants or the use of back-up capacity from large storage, would be more cost competitive to balance the grid compared to decentral smaller scale demand side measures which would need to be aggregated to support grid stability.

Therefore, in the services sector, only very limited appliances and technologies (energy services) with a large electricity demand would be effectively used for demand side measures such as cold storage houses, large night storage heater or heat pumps, and large ventilation and air-conditioning systems.

[3] The interdependencies between energy system and economic growth will not be considered in REFLEX.

As of today, these large energy services make up only a small share of the electricity demand from the services sector in Europe, whereas only a fraction of this demand is theoretical available for demand side management (DSM) measures. In a “centralized world”, this very limited flexibility potential would be considered as stable. Depending on the country regulation for participation in the balancing market, this DSM potential is already tapped as of today. These DSM options would be centrally controlled and marketed on balancing markets where grid operators are the sole responsible for requesting the needed DSM capacities.

Transport and power-to-x-technologies could be additional flexibility options, although their relevance could be negligible. Flexibility options within the mobility sectors will mainly occur with the diffusion of electric mobility. Within a “centralized world” a broad market penetration seems unlikely. Whether power-to-x-technologies will play an important role, depends on the abundance of off-peak electricity, next to technical restrictions, like flexibility of downstream technologies and low energy efficiency in case of re-electrification. The revenues from selling off-peak stored electricity have to match the high annualized investment and operating costs, at least. The abundance of off-peak electricity in a “centralized world” may be low, if the above mentioned flexibility options will be successfully applied.

Flexibility options in a “de-centralized world”

In the “de-centralized world”, the generation capacities would be spatially more evenly distributed as well as the storage capacities. Therefore, the grid infrastructure for large distance transmission would also be limited. The probability for precise generation forecasting would decrease due to the high number of participants and the high uncertainty on effective available renewable generation (downtime of plants). All together arguments for an increasing need for demand side flexibility. In addition to the already mentioned energy services for DSM in the “centralized world”, additional technologies would be integrated like air-conditioning and ventilation systems, freezers and refrigerators, other white appliances, small night storage heater and heat pumps, and other tertiary sector processes. By including these technologies, the theoretical potential for DSM increases. To which extent needs to be investigated.

The above mentioned DSM potential focusses mainly on households and tertiary sector. The DSM potential of industry under such scenario is unclear. The potential is determined by amongst others the production process (batch vs. continuous), produced product (storable over hours vs. storable less than an hour vs. non-storable), company-internal workflows (flexible working hours vs. non-flexible ones), provision of energy (internal vs. external and batch vs. continuous) and organization of supply and demand chains (just-in-time vs. batch). In the “de-centralized world”, a strong ability of industrial process flexibility is assumed, however, limited by thermo-dynamic and economic constraints. The latter means, that technical flexibility potentials are only exploited as long as these are not contradicting the profit-orientation of industry companies. To which extent the flexibility potentials are present needs to be investigated.

The relevance of flexibility options within mobility sectors will mainly depend on the market penetration of electric mobility as well as mobility services and autonomous driving cars in car sharing fleets. On the one hand, fleet operators can shift charging processes during the day taking the passenger transport demand situation into account. On the other hand, the availability of better infrastructure allows also private users to adapt their preferences to a different daily charging profile. Compared to today's charging strategies (mostly at home and in the evening), electric cars can be charged during off-peak hours.

As mentioned above, the abundance of available off-peak electricity and some technical impediments could reduce the role of power-to-x-technologies as a flexibility option. Furthermore, as long as no small scale applications of power-to-X technologies are developed, the demand for electricity by the technology could outmatch the available off-peak electricity within a region.

4 Conclusions

According to the political aim of most Member States of the EU and the one of the European Commission, the future energy system will be dominated by a high share of RES, of which wind and solar energy are characterized by high intermittency. To manage this system, economic flexibility potentials have to be identified and quantified. Within REFLEX the analysis of the flexibility potential will be based on two scenarios, which are presented in this Policy Brief. The first consideration shows a high interrelationship between the design of the energy system and the flexibility potentials. However, a further elaboration of the interdependencies is necessary.

Considering the energy system as a socio-technical system, both discussed scenarios are based on different societal demands regarding the underlying aims of the transformation process, i.e. whether "only" climate change shall be taken into account or whether the transformation is also used to realize a "more democratic" provision of energy.

Both scenarios characterize a possible pathway for transformation with highlighting two probable characteristics under the assumption that the overall framework will not be altered by reality until 2050.

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