Energy Proceedings
2022
ISSN 2004-2965

Local and decentralized or global and centralized: assessment of two paradigms for the European power system decarbonization

Victor Guillot*, Gildas Siggini, Edi Assoumou

MINES Paris-PSL University, CMA - Centre for Applied Mathematics, Rue C. Daunesse, 06904 Sophia Antipolis, France
*Corresponding author: victor.guillot@minesparis.psl.eu

ABSTRACT

The increasing share of renewable energy systems (RES) at the European scale enables the shift from a centralized to a decentralized power system with small units located close to consumption sites. Decentralized power systems enhance social acceptance, however it requires a deep change of the current grid. This study explores with the model eTIMES-EU the feasibility conditions, barriers and benefits of this change with a land use perspective.

Keywords: Power system, Europe, TIMES, Energy planning, Decentralized

1. INTRODUCTION

The European grid was originally built in a centralized manner on two aspects. First, regarding its architecture, the electricity network has been designed in a manner that high-powered generation facilities (>100MW) were connected to a transmission network. In terms of decision-making, the development of the network is the result of interaction between governments and few large energy companies. Moreover, the development of interconnections pushed by the EU for a greater integration of European countries reflects the centralized approach for decision making and installation of large infrastructures. However, the power system transition to carbon neutrality requires to stop electricity production from fossil fuel power plants and the emergence of RES such as wind and photovoltaic (PV) in order to reduce emissions from combustion. Although RES may be subject to local protests and a lack of social acceptance, they offer the possibility of moving towards a decentralized electrical system that would reduce the need for a large grid. This decentralized approach to power generation in terms of both infrastructure and decision making is seen as a way to improve social acceptance. However, there are barriers that limit decentralization like past or planned investments in certain infrastructures such as nuclear power plants or transmission networks. Moreover, balancing the network at local levels requires additional investments in storage and dispatchable power units. In addition, the use of RES such as onshore wind or PV, which are less energy dense than nuclear power, may lead to an increase in the surface area used for power generation in certain countries that have chosen to shift to this type of technology. Finally, countries that have chosen to remain on a centralized network development may lose out in terms of investment or employment because they cannot export electricity to their neighbors.

Spatial dispatching has been investigated in few studies. [1] focuses on trade-offs between efficiency and equity in Germany. The authors propose a spatially explicit dispatch of PV and wind that meet a given electricity production for renewables. Then they compute indicators like minimal distance to infrastructures or Gini coefficient applied to equity. [2] investigates electricity production in 2035 in Switzerland. They also use a spatially explicit model and consider investment distribution in addition to equity in production. [3] analyses trade-offs between regional or continental operation of 100% renewable European grid for one year. They provide information on cost and technical requirements. [4] focuses on geographical distribution of infrastructures for an entirely renewable power system for one year. It compares scenarios with different level of equity or autarky to a cost optimal scenario. [5] takes a slightly different approach by building three scenarios that represents different paradigms of grid development for the UK power system development between 2010 and 2050. They look at different dimensions like capacity or investment distribution over UK regions.

While these studies give valuable insights on a spatial distribution of infrastructures, only [5] considers transition paths, the others are limited to a one year optimization which fails to consider deployment rate or dependency to past investments. Moreover, only [3], [4] cover Europe with its interconnexions which play a major role in balancing the production at a continental scale.

These two studies consider a fully renewable power system.

This study proposes to assess at the European scale implications of a transition towards a decentralized production with a carbon neutrality constraint in 2050. The elements that are considered are the total annualized cost, total land-use and investments distribution between countries. The goal is to consider the system in its globality but also to look into individual situations.

2. METHODOLOGY

2.1 Model

eTIMES-EU is a bottom-up optimization model which represents the European power system[6]. It considers the European Union continental countries plus Iceland, Norway, Switzerland and UK. The goal of this model is to assess scenarios on the power system transition. It makes investment and production decisions in order to minimize the total actualized cost of the system. This type of model is well suited for this study because the full description of technologies and relations between them enable a precise observation of a constraint on land.

The period going from 2016 to 2050 is sliced in 5-year periods, then each year is represented by 64 periods that consider seasons. Each period is made of two typical days which represent the week or the week-end. These days are sliced in 8 time step of three hours to capture the variability in capacity factors. The calibration of the starting year and technology assumptions are based on data coming from the EU commission, the ENTSO-E and the IEA. Demand load curves come from [7] and correspond to the low electrification scenario. Regarding interconnections, we allow the construction of additional capacities compared to projects up to 2040 in the TYNDP2020[8].

We added in the model a land variable linked to new power plant investments, which enables to create scenarios where the total land use can be constrained.

2.2 Scenario description

We used the definition of decentralization from [9] to build our scenarios. Decentralization refers to the type of technologies but also to the process of building and the development of the grid.

We built the decentralized scenarios in an iterative process. While we did not know if a fully decentralized scenario was achievable, we started with a scenario where offshore wind, nuclear, CCS and PV large scale were not available for building starting from 2030. These technologies are linked to a centralized grid on two aspects: they are of large capacity and are designed, installed and managed by big energy utilities for most of projects. We also modified parameters related to onshore wind, in the decentralized scenario, new capacities of onshore wind available for constructions are small individual wind turbines of a unitary power of 20kW. Its investments cost is roughly multiplied by 5 in comparison to large scale onshore wind[10]. Because the model had difficulties to find a workable solution we used this scenario as a base to build a new one. The *Decentralized+* scenario is built in a manner that the same capacities as in the *Decentralized* scenario of decentralized technologies will be installed by 2050 and the rest will be completed by the remaining technologies. In other words, decentralized technologies are prioritized compared to conventional one to their maximum rate of deployment and potential. The next step is to fill the gap with others technologies.

Furthermore, to reflect the fact that generation is close to consumption and favor national production, we limit annual imports for each country to the shares of the national demand that are seen in 2016.

In order to consider social acceptance in a centralized scenario, we set a constraint on the land-use increase. The rationale is that social acceptance enhanced by limiting the land sprawl without any change on governance. All scenarios are built to reach carbon neutrality.

Table 1 Scenario description

Scenario	Technologies	Interconnexions	Land-use
Centralized	All	No restriction	No restriction
Centralized_x2	All	No restriction	Increase ≤2
Decentralized	No nuclear, offshore wind, PV ground, CCS	Imports limited to shares observed in 2016	No restriction
Decentralized+	Priority to onshore wind decentralized and PV roof, other technologies authorized as complement	Imports limited to shares observed in 2016	No restriction

3. RESULTS

3.1 Generation mix

The model finds two optimal solutions for both centralized scenarios. However, it fails to find a workable solution for the *Decentralized* scenario. About 6% of the production is linked to virtual imports of electricity which means that the optimization problem is too constrained and the model has no other choice than to create dummy electricity production. These virtual imports are mostly done in winter season timeslices, where demand peaks are the highest. If we transpose this to a real electricity system, it means that the operation of the power system has to proceed to load shedding. These virtual imports allow the model to respect the equilibrium between load and production. The situation is corrected in the *Decentralized+* scenario where dummy imports are replaced by production of others technologies.

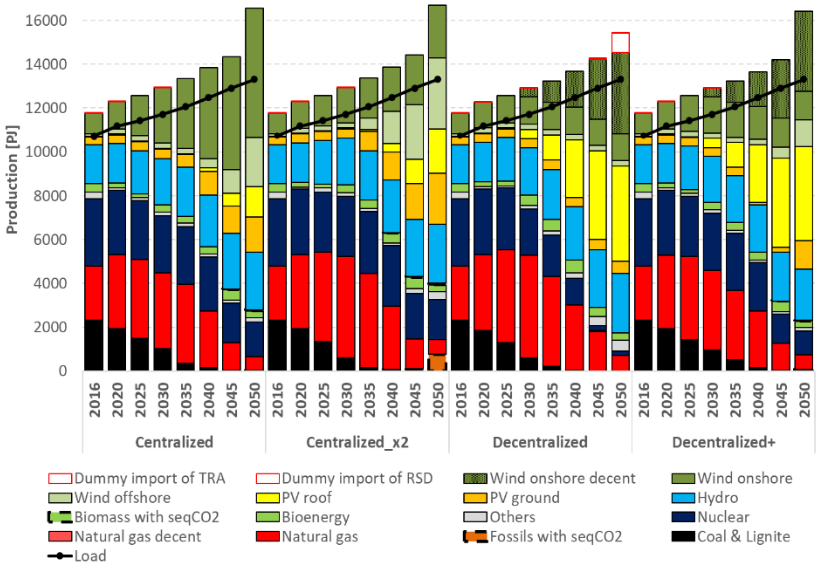

Fig 1 Generation mix for the four scenarios

3.2 *Capacity installed*

Installed capacities vary significantly with scenarios. We observe that the two centralized scenarios have more capacities installed for natural gas, nuclear and PV. This can be explained by the fact that dummy imports chosen by the model at some points reduces the need for dispatchable capacities during peak periods.

Regarding the two centralized scenarios, the land constraint forces the model to install more PV and offshore wind than in the land unconstrained scenario. Installed capacities of onshore wind is also reduced by more than half in the constrained centralized scenario in comparison to the unconstrained scenario.

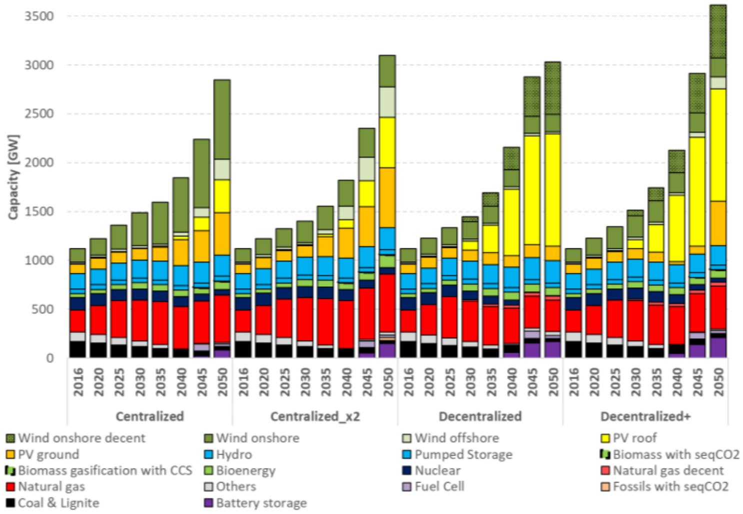

Fig 2 Capacity installed for the four scenarios

There are significant differences between the decentralized scenarios. *Decentralized+* has more than 500GW of total capacity installed in comparison to the *Decentralized* scenario. One reason for this is linked to the dummy imports in the *Decentralized* scenario which enabled the model to not size the power system for demand peaks. The other reason is related to the modeling, while we fixed the capacity of decentralized PV and onshore wind, other capacities can only be added to existent one which contributes to a global increase. Main contributions of the additional capacities are by order of magnitude PV ground, natural gas, offshore wind, nuclear and onshore wind

3.3 *Costs*

Table 2 Absolute costs per scenario and relative difference with the *Centralized* scenario

Scenario	**Total annualized cost [M€]**	**Cost relative difference with Centralized scenario**
Centralized	6008669.53	-
Centralized_x2	6057864.14	0.8%
Decentralized	6647827.53	11%
Decentralized+	6215926.54	3%

We noticed a significant difference of the total annualized cost between the *Decentralized* scenario and the two centralized scenarios. The *Decentralized* scenario cost is roughly 11% higher than the *Centralized*. Expensive dummy imports increase the total annualized cost. The cost difference is reduced in the *Decentralized+* scenario. The land constrained scenario is about 1% more expensive than the not constrained one.

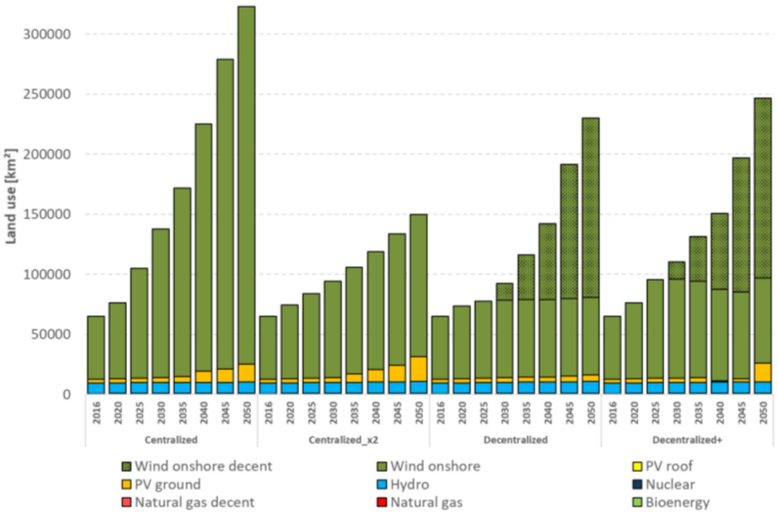

Fig 3 Land use for the four scenarios

3.4 *Land use*

Concerning land-use, both *Centralized_x2* and decentralized scenarios reduce the total land-use in comparison to the *Centralized* scenario. This gain in the *Centralized_x2* mainly comes from the land constraint which limits the installation of new onshore wind capacities that have a high total land-use. In the *Decentralized* scenario, the limitation of new capacities of PV ground and onshore wind paired with the development of decentralized onshore wind which has a lower total footprint reduce the land used by the power system. The main difference between the two decentralized scenario is related to the higher installed capacities of PV ground in the *Decentralized+* scenario.

3.5 *Exchanges*

There are major differences in 2050 between centralized and decentralized scenarios due to the severe constraint on exchanges in the decentralized cases. The amount of trades is drastically reduced in the decentralized scenarios. For instance electricity imports are divided by 7 or 10 in Germany between centralized and decentralized scenarios. Italy and Belgium have their imports divided by more than 2. We also notice shifts in trades, countries like Denmark and the Netherlands which are net exporters in the centralized scenarios become net importers in the decentralized cases. These changes can have an impact locally in terms of industry and national investments.

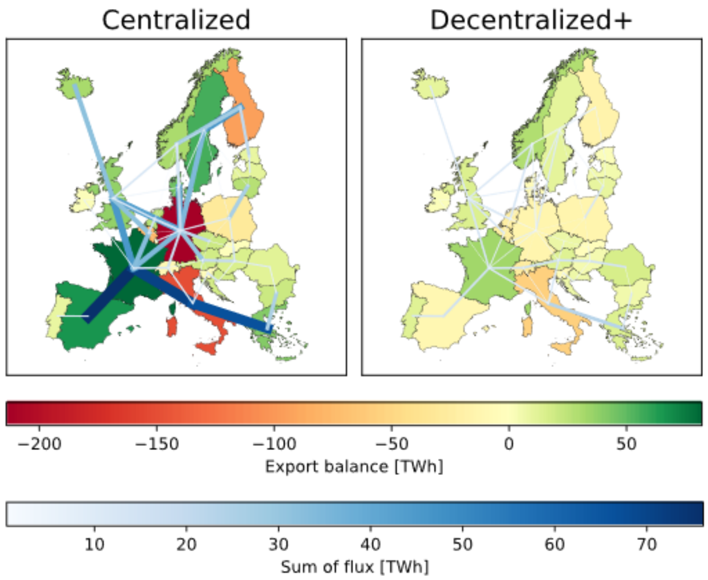

Fig 5 Exchanges by country and scenario in 2050

3.6 *Industry and investments*

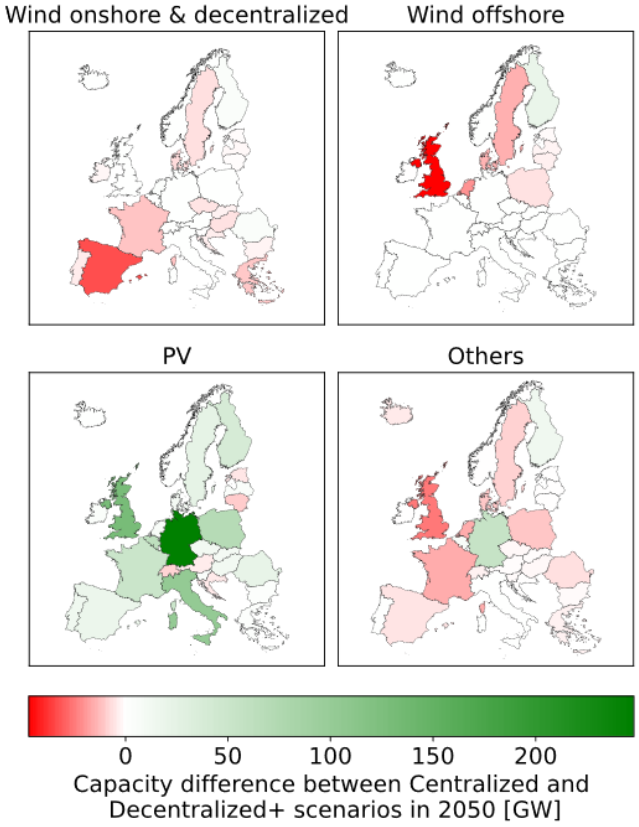

Fig 4 Capacity installed difference in 2050 between *Centralized* and *Decentralized+*

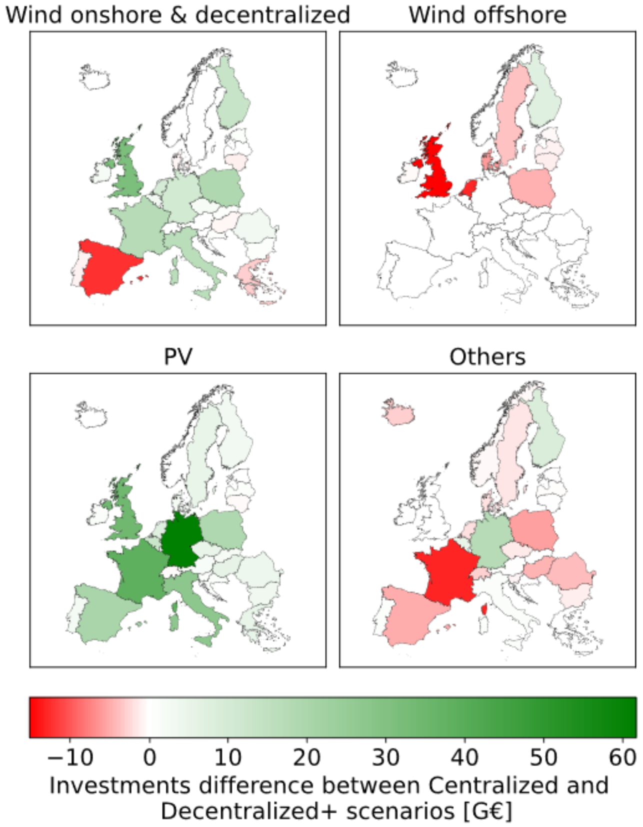

Fig 6 Total cumulative undiscounted costs difference between *Centralized* and *Decentralized+*

While results show that a mix with a high level of decentralization is achievable, it requires to take structuring options on the grid development that will have an impact on national economies and industries. However, there are economic winners and losers that may favor or hinder the implementation of a policy. For instance, decentralized scenarios will lead to higher national investments for countries which create economic spillovers but also higher electricity costs for consumers. Nonetheless some countries like the Netherlands and Denmark attract less investments in decentralized scenarios because they cannot valorize their offshore wind potential, a more centralized technology.

Moreover, the nature of capacities installed drastically changes between centralized and decentralized scenarios for specific countries. While the vast majority of countries has to build new PV capacities in decentralized scenarios, core power system technologies for countries may change fundamentally. This is striking for the UK which has a strong differentiation between centralized and decentralized developments. Centralized scenarios favor offshore wind to PV roof while decentralized scenarios call for the opposite.

4. DISCUSSIONS

4.1 *Feasability*

We have seen that it was possible to build a power grid with a high level of decentralization with the scenario *Decentralized+.* Nevertheless, it requires very ambitious development policies. The two centralized scenarios are also ambitious in terms of deployment rates but this situation hides differences in terms of number of projects. The two centralized scenarios tend to have a lower number of large size power generation facilities than the decentralized scenario which tend to be made of lower size but more numerous production sites. Considering an average size of 20kW for a decentralized wind turbine and a 2.5MW of a normal onshore wind turbine, the centralized scenarios require about 320000 wind turbines while the decentralized 27 million. For PV rooftop, considering an average size of 10kWp per households yields to install solar panels on more than 110 million sites in the decentralized scenarios.

There are few methods that can reduce the overall size of the grid in the decentralized case that are not explored in this study. Demand shift or reduction may lower the total capacity to install.

4.2 *Policy implications*

Results may have several policy implications:

-advantages linked to either centralized or decentralized development tend to change depending on the country. These differences of point of view may lead to a disorganized development of the power system which will emphasizes drawbacks of both development schemes. The choice of centralization/decentralization should be further discussed by European countries collectively.

-the development of the grid is significantly affected by the chosen policy. In the centralized scenarios, it enables to cost efficiently integrate variable renewables while in the decentralized scenarios, the use of the grid is limited.

-while decentralized technologies tend to enhance social acceptance, it requires massive installations of small size production sites. The social acceptance of this power system development might not be guaranteed and should be further investigated.

4.3 *Limitations of this study*

While our method enables to assess transition pathways, it has some limitations on the representation of the power system. Our model considers only border exchange capacities and overlook the development of internal national grids. Furthermore, land-use associated with grid connections are not taken into consideration. Another limitation is the level of electricity demand. Demand values considered correspond to a limited electrification. Results may change with a higher level of electrification.

5. CONCLUSION

The study shows key points to be considered when implementing a policy of decentralization of power generation facilities. If it improves social acceptance, it implies a higher cost, possible failures in the supply of electricity and requires highly voluntarist development of capacities policies. Nonetheless making compromises on some technologies may help to achieve supply security and still keep an important amount of decentralized technologies. Some key infrastructures, like the transmission grid, are strongly affected by the chosen development path. Their roles need further investigations.

REFERENCE

[1] M. Drechsler, J. Egerer, M. Lange, F. Masurowski, J. Meyerhoff, and M. Oehlmann, “Efficient and equitable spatial allocation of renewable power plants at the country scale,” *Nat Energy*, vol. 2, no.

9, pp. 1–9, Jul. 2017, doi: 10.1038/nenergy.2017.124.

[2] J.-P. Sasse and E. Trutnevyte, “Distributional trade-offs between regionally equitable and cost-efficient allocation of renewable electricity generation,” *Applied Energy*, vol. 254, p. 113724, Nov. 2019, doi: 10.1016/j.apenergy.2019.113724.

[3] T. Tröndle, J. Lilliestam, S. Marelli, and S. Pfenninger, “Trade-Offs between Geographic Scale, Cost, and Infrastructure Requirements for Fully Renewable Electricity in Europe,” *Joule*, vol. 4, no. 9, pp. 1929–1948, Sep. 2020, doi: 10.1016/j.joule.2020.07.018.

[4] F. Neumann, “Costs of regional equity and autarky in a renewable European power system,” *Energy Strategy Reviews*, vol. 35, p. 100652, May 2021, doi: 10.1016/j.esr.2021.100652.

[5] F. G. N. Li, S. Pye, and N. Strachan, “Regional winners and losers in future UK energy system transitions,” *Energy Strategy Reviews*, vol. 13–14, pp. 11–31, Nov. 2016, doi: 10.1016/j.esr.2016.08.002.

[6] S. G. Simoes *et al.*, “Climate proofing the renewable electricity deployment in Europe - Introducing climate variability in large energy systems models,” *Energy Strategy Reviews*, vol. 35, p. 100657, May 2021, doi: 10.1016/j.esr.2021.100657.

[7] Directorate-General for Climate Action (European Commission) *et al.*, *EU reference scenario 2016: energy, transport and GHG emissions : trends to 2050*. LU: Publications Office of the European Union, 2016. Accessed: Jul. 06, 2021. [Online]. Available: https://data.europa.eu/doi/10.2833/001137

[8] ENTSO-E, “TYNDP2020 Completing the map – Power system needs in 2030 and 2040,” p. 70, Aug. 2021.

[9] M. Wolsink, “Framing in Renewable Energy Policies: A Glossary,” *Energies*, vol. 13, no. 11, Art. no. 11, Jan. 2020, doi: 10.3390/en13112871.

[10] T. Stehly, P. Beiter, and P. Duffy, “2019 Cost of Wind Energy Review,” *Renewable Energy*, p. 86, 2020.