The Role of Transmission and Energy Storage for Integrating Large Shares of Renewables in Europe

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See footnotes at end of text.

Ambitious goals for decarbonizing our energy supply necessitates a large-scale deployment of renewable energy (RES) power generation. The most prominent RES technologies, wind power and solar power, are intermittent and non-dispatchable by nature, which impose new challenges to power system planning. Significant shares of our power generation will be as reliable as the weather. An important consideration in power systems is balancing, preserving a match between generation and load at all times while safely operating the grid by not overloading its components. With large shares of fluctuating and non-dispatchable power generation throughout the system, the ability to transfer power from where it is produced to where it is used will become increasingly complex. Emerging technologies on the demand side, such as utility grade batteries and smart grid technology provide new opportunities by offering services which have previously been of limited availability to the electricity sector, energy storage and demand side management. While the grid provides the system with spatial balancing of supply and demand, energy storage allows for temporal balancing. However, these balancing services interact. In particular, in a system with much renewables and a weak grid the possibility of sharing generation resources is low, but energy storage can help alleviate local shortage situations. With a strong grid the need for energy storage for balancing can potentially be much lower.[1]

In order to shed light on the interacting roles of transmission and energy storage as means to integrate renewables in Europe we present a brief analysis of a few selected scenarios using the EMPIRE[2] model [1]. This model is a dynamic capacity expansion model for the European power system based on stochastic programming. Using projections for demand development, fuel prices and power generation technology development EMPIRE computes the least-cost investment plan, with five-year increments, for generation capacities, cross-border transmission corridor capacities and energy storage (power and energy) capacities. Embedded in the model is an economic dispatch optimization for the European system, which drives the economic valuation of the investment options. The geographical detail level in EMPIRE is national (covering 31 countries).

The scenarios analyzed (Table 1) have three levels of transmission reinforcement strategies represented: high, limited and no expansion. In the limited transmission scenario expansion of cross-border capacities between countries is constrained to 10 % of the 2010 capacity plus 300 MW for every five year investment step. For the high transmission scenario a 200 % increase of the 2010 capacity plus 1 GW is allowed for each connection every fifth year. The rationale behind these constraints is to form a conservative infrastructure plan while still not limiting development of weak connections too extensively. The scenarios either allow for energy storage to be deployed or not. Four energy storage technologies are available, two technologies where power and energy capacity are individually decided (each with individual costs) and two large-scale battery technologies[3] in which only the energy component is assumed to have a cost. An initial installed capacity of 44 GW/2.6 TWh pumped storage (power and energy capacity) is assumed installed in the European system in 2010.

A common assumption for all the scenarios investigated is that the direct emissions from the power sector should be linearly reduced to 90% below 2010 levels by 2050. Low carbon technologies other than renewables are assumed to play an insignificant role in decarbonizing the European power sector. Nuclear power is constrained to remain close to current levels, and carbon capture and storage is assumed not to be commercially available. Assumptions regarding fuel price and electricity demand development are based on the 2013 EU reference scenario published by the European Commission [2]. Parameters and cost assumptions for generation technologies implemented in EMPIRE coincide with the data sets published in [3].

In this analysis we focus on a few selected metrics to understand the effect of transmission and energy storage options on integration of intermittent renewables (iRES). These metrics are the optimal iRES share in the 2050 generation mix, curtailed generation and the deployment of energy storage capacity in the system. Table 2 shows that a 90 % emission reduction will require a significant share of wind and solar in the EU generation mix, 54-63 %. Scenarios 5 and 6 show that if this increase in intermittent generation is not accompanied by massive expansion of cross-border transmission capacity the total cost to the electricity sector will be high, potentially in the hundreds of billions euros. Energy storage can be seen to be an important technology if the transmission system is not strengthened. In scenario 6, where

	Transmission		
Energy storage	High	Limited	No expansion
Available	Scenario 1	Scenario 3	Scenario 5
Not available	Scenario 2	Scenario 4	Scenario 6

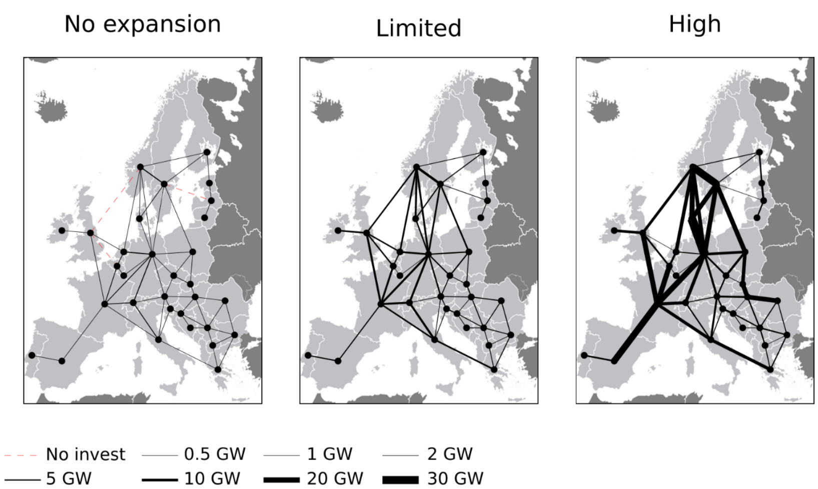
Table 1: Scenarios analyzed with the EMPIRE model.

	Δ cost (compared to scenario 1)	iRES generation share in 2050	Curtailed energy 2050		Added transmission by 2050	Added energy storage by 2050	
			Wind	Solar		Power	Energy
	[bn€$_{2010}$]	[%]	[TWh]	[TWh]	[GW]	[GW]	[GWh]
Scenario 1		56	8	7	466	20	1
Scenario 2	1	56	11	7	470		
Scenario 3	63	54	15	6	192	33	90
Scenario 4	64	54	28	8	192		
Scenario 5	182	56	169	43		133	2046
Scenario 6	274	63	490	153			

Table 2: Selected results from the analysis

neither new transmission capacity nor energy storage is allowed, there is a significant increase in the renewable generation share over the other scenarios. The reason is simple, when there is limited potential to transfer or store electricity in a system with high renewable generation shares, capacities have to be scaled such that local generation can make a significant contribution to cover the local load peaks. Unless the peak generation for the renewables is highly correlated with the peak demand this strategy will result in capacity which under-utilized at times when generation is high and the load is low. The amount of curtailed energy from renewables, i.e., the generation lost due to the system's inability to absorb it, is 643 TWh in scenario 6. To put this number into perspective, in 2014 the total generation from wind power in EU-28 was in 247 TWh [4]. By enabling energy storage to be deployed in scenario 5, there is a much better utilization of the intermittent resources, and the curtailed generation see a threefold reduction.

The amount of increased transmission capacity found optimal by EMPIRE is largely unaffected by the availability of energy storage. In the 'limited transmission' scenarios, 3 and 4, the total new capacity by 2050 is 192 GW. In the 'high transmission' scenarios, 1 and 2, the optimal transmission more than twice that of the limited case, 466 GW with energy storage investment allowed, and 470 GW in the scenario without. In both the limited and high transmission reinforcement scenarios the infrastructure investments are substantial compared to the total transmission capacity in 2010, which was 67 GW. Figure 1 shows how the transmission corridors in Europe are developed in each scenario with energy storage.



The main conclusion we can draw from this analysis is that in terms of renewable integration at levels above 50 % in Europe, energy storage is an expensive alternative solution to grid reinforcement. However, even the limited transmission expansion scenario considered here entails increasing the capacity to a level close to four times the capacity in the current system. Although these infrastructure investments are part of the cost-efficient solution, we cannot be guaranteed that they will in fact materialize. Should the infrastructure development fall behind, energy storage can be used as a recourse option.

Footnotes

[1] Other services from energy storage such as energy arbitrage and ancillary service provision can still have significant value to the system but is out of the scope of this discussion.

[2] European Model for Power System Investments with (high shares) of Renewable Energy

[3] Using published cost and technical parameters for Tesla's Powerpack battery and the Eos Aurora 1000|4000 grid-scale energy storage system. See https://www.teslamotors.com/powerwall and http://www.eosenergystorage.com/technology-and-products/ for more information.

References

1 Skar, C., G. L. Doorman, and A. Tomasgard. 2014. "The future European power system under a climate policy regime." In EnergyCon 2014, IEEE International Energy Conference, 337–344. doi:10.1109/ENERGYCON.2014.6850446

2 European Commission. 2014. EU energy, transport and GHG emissions trends to 2050. Reference scenario 2013. doi:10.2833/17897.

3 Zero Emissions Platform. 2013. CO2 Capture and Storage (CCS) – Recommendations for transitional measures to drive deployment in Europe. European Technology Platform for Zero Emission Fossil Fuel Power Plants. Available from http://www.zeroemissionsplatform.eu/library/ publication/240-me2.html.

4 EUROBSERV'ER. 2015. Wind Energy Barometer 2014. Available from http://www.eurob