Assessing the potential benefit of energy storage in emission constrained power markets using equilibrium modeling

Askeland, M., Jaehnert, S., & Korpås, M.

Citation for the published version (APA 6th)

Askeland, M., Jaehnert, S., & Korpås, M. (2017, June). Assessing the potential benefit of energy storage in emission constrained power markets using equilibrium modeling. In *European Energy Market (EEM), 2017 14th International Conference on the* (pp. 1-6). IEEE.

DOI: 10.1109/EEM.2017.7981905

Assessing the Potential Benefit of Energy Storage in Emission constrained Power Markets using Equilibrium Modeling

Magnus Askeland
and Stefan Jaehnert
SINTEF Energy Research AS
Trondheim, Norway
Email: magnus.askeland@sintef.no

Magnus Korpås
Department of Electric Power Engineering
Norwegian University of Science and Technology
Trondheim, Norway

***Abstract*—An equilibrium model of the energy market is extended by a carbon emissions market. In addition, the mix of renewable energy sources is optimized given a limit on total generation. These two new features are integrated into an existing model to assess the effects of a carbon emissions market in a case study of the northern European power system. First, a fixed carbon emissions tax is deployed, revealing that carbon emissions can be greatly influenced by the availability of energy storage. Further, a carbon emission quota is implemented and the tax necessary to enforce the limit is calculated by the model. Based on the case studies, it is discussed how quota level and the availability of energy storage influence, among others, optimal system design and power market stakeholders.**

I. Introduction

Several countries proclaim ambitious targets regarding decarbonization of the power system. Considering the lifetimes of assets, the European Union stresses that many of the power system investments made today will last well beyond 2050 [1]. Hence, to keep the long term costs at a reasonable level, a future power system with a lower emission intensity need to be considered when investment decisions are made.

This paper is motivated by related work on the topic which include a profit maximizing carbon capture power plant operating in a combined energy and carbon emissions market presented in [2]. It was found that a carbon capture power plant can increase the profitability by applying flexible operation considering both the energy market and a cap and trade carbon emissions market.

Further, [3] compute low-carbon system dispatch by considering a set of power producers including carbon capture power plants. The capacities are fixed while dispatch is optimized, treating carbon emissions as a type of dispatchable resource.

In the following paper, these research questions are considered to assess how energy storage may contribute to carbon emissions reductions in the power system:

The presented work is part of the research project CEDREN-HydroBalance (228714/E20) funded by the Norwegian Research Council and industry partners.

978-1-5090-5499-2/17/$31.00 ©2017 IEEE

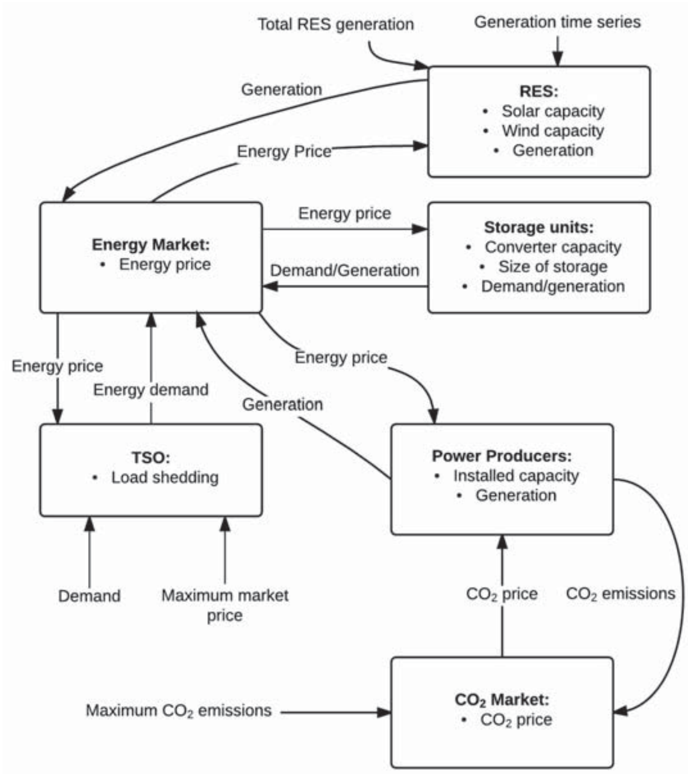

Fig. 1. Model schematic

- How is the technology mix influenced by carbon emissions pricing?
- To which extent will the availability of energy storage technologies influence the carbon emissions level and technology mix?
- If a carbon emissions quota is applied, how is the equilibrium influenced by the availability of energy storage?
- How is the market equilibrium affected by changes in the carbon emissions quota?

The motivation is to identify market conditions that can contribute to achieving the ambitious climate targets for 2050 and onward set by the European Union [4].

The fundamental power market model presented in [5] is extended by a carbon emission market mechanism and an optimizations of renewable energy sources (RES). Investments and dispatch are co-optimized in the model which include thermal units, storage units, RES production and a demand side. These stakeholders are coupled through markets, including energy and carbon as illustrated in Fig. 1. The fixed costs, variable costs and carbon emissions costs need to be recovered by participation in the energy market. In the case that the costs can not be recovered, there will be no investments in uncompetitive technologies.

The rest of this paper is structured as follows. First, the methodological framework regarding RES and carbon emissions market is presented in section II. Further, a case study with high levels of RES is conducted in section III before conclusions are drawn in section IV.

II. Methodology

This section will explain the main contributions in this work; the implementation of a carbon market and RES mix optimization. The model consist of profit maximizing market stakeholders under a perfect market assumption where capacities and dispatch are endogeneous variables. For a more elaborate description of the underlying model which is illustrated in Fig. 1, see [5].

RES are modeled without considering investment costs. However, there is a limit on total potential RES production. Due to the energy limitation there is a trade-off between the different RES technologies and the model will determine the optimal RES-mix based on how the production profiles coincides with the market prices.

Regarding the carbon emissions market, either a carbon emissions tax or a carbon emissions quota can be applied. For example, the level of carbon emissions will be determined by the model in the case that a carbon tax is applied.

A. Nomenclature

In the mathematical description of the developed model, the following symbols are used:

1) Sets:

- f $\in$ F: Set of thermal power producers
- h $\in$ H: Set of time steps
- r $\in$ R: Set of RES technologies
- s $\in$ S: Set of storage units

2) Variables:

- cap_r^{inst} [MW]: RES capacity
- $gen_{f,h}$ [MWh/h]: Thermal output
- $gen_{r,h}$ [MWh/h]: RES output
- π_r [EUR]: RES profit
- κ [EUR/MWh]: Scarcity rent for RES limit
- λ_h [EUR/MWh]: Energy price in the energy market
- $\mu_{r,h}$ [EUR/MW]: Scarcity rent of RES capacity
- τ [EUR/ton]: Emission tax

3) Parameters:

- DEM_h [MWh/h]: Demand data
- E_f [ton/MWh]: Emission factor
- $INJ_{r,h}$ [MWh/h/MW]: RES potential production
- Q^{MAX} [ton]: Emission quota
- RES: Potential RES as fraction of total demand.
- T_h [h]: Length of time step

B. Renewable Energy Sources

RES will produce at positive market prices according to equation (1). Generation from RES is limited by the installed capacity multiplied with a time series value according to equation (2). The amount of RES is governed by equation (3), which is the condition that potential generation across all RES technologies should not exceed a given fraction of total demand. This translates to an optimization of the RES mix favoring production at high prices at the cost of producing less at lower prices. While this formulation does not include fixed costs for RES technologies, investing in one technology has a alternative cost since it reduces the investments in other RES technologies. A reason for choosing this approach is that we aim to assess a system with high levels of RES, while the future fixed costs for RES technologies are uncertain and rather hard to predict.

$$\forall r : \text{Maximize: } \pi_r = \sum_{h=1}^{H} gen_{r,h} * \lambda_h * T_h \tag{1}$$

Subject to:

$$\forall r, \forall h : gen_{r,h} \leq cap_r^{inst} * INJ_{r,h} \tag{2}$$

$$\sum_{r=1}^{R} \sum_{h=1}^{H} T_h * cap_r^{inst} * INJ_{r,h} \leq RES * \sum_{h=1}^{H} T_h * DEM_h \tag{3}$$

The linear problem in equations (1) to (3) is reformulated as a linear complementarity problem (LCP) in equations (4) to (7). The LCP formulation is the input to the GAMS modeling language. Similar conditions are derived for the other market stakeholders depicted in Fig. 1.

$$\forall r, \forall h : \mu_{r,h} - \lambda_h * T_h \geq 0 \perp gen_{r,h} \geq 0 \tag{4}$$

$$\forall r : -\sum_{h=1}^{H} INJ_{r,h} * \mu_{r,h} + \kappa * \sum_{h=1}^{H} * T_h * INJ_{r,h} \geq 0 \perp cap_r^{inst} \geq 0 \tag{5}$$

$$\forall r, \forall h : cap_r^{inst} * INJ_{r,h} - gen_{r,h} \geq 0 \perp \mu_{r,h} \geq 0 \tag{6}$$

$$RES * \sum_{h=1}^{H} T_h * DEM_h - \sum_{r=1}^{R} \sum_{h=1}^{H} T_h * cap_r^{inst} * INJ_{r,h} \geq 0 \perp \kappa \geq 0 \tag{7}$$

Generation is triggered if the market price covers the scarcity rent for generation capacity according to equation (4). In practical terms this means that generation from RES will attempt to cover the demand as long as there are available RES generation capacity, since it has the lowest variable cost. However, the formulation ensures that RES will curtail the production during time steps with excess production potential to avoid overproduction.

Optimal installed RES capacity is determined according to equation (5) which states that capacity will increase if the scarcity rent for generation capacity is enough to cover scarcity rent for the RES limit. In other words, the equilibrium will be the optimal balance between the different RES.

Equations (6) and (7) are based on the restrictions of the LP and express how the scarcity rents for generation and RES limit are calculated through the dual variables.

C. Emissions Market

A second focus to a carbon emissions tax is to consider a carbon emissions quota. The variable cost $E_f * \tau * gen_{f,h}$ is added to the objective function of the thermal power producers. E_f is the carbon emissions from the generation of one MWh of energy and is calculated based on the fuel utilized and technology efficiency.

Further, τ is the carbon market clearing price, which can either be fixed as an exogenous parameter, or calculated as a result of enforcing a carbon emissions quota. Equation (9) is the LCP formulation of the emission constraint in equation (8).

$$\sum_{h=1}^{H} \sum_{f=1}^{F} T_h * E_f * gen_{f,h} \leq Q^{MAX} \tag{8}$$

$$Q^{MAX} - \sum_{h=1}^{H} \sum_{f=1}^{F} T_h * E_f * gen_{f,h} \geq 0 \perp \tau \geq 0 \tag{9}$$

The carbon emissions market can influence the generation mix by increasing the variable costs of power producers according to their emission intensity. Thus, technologies without significant carbon emissions will be relatively cheaper. As a result of the carbon emissions tax, the competitiveness between power producers will be altered by creating a bias against technologies with a high emission intensity, enforcing the emission limit at the lowest possible cost.

III. Case Study

The following case study of northern Europe comprises Belgium, France, Germany and the Netherlands without any network restrictions. Potential PHES is provided from Norway through a limited HVDC connection while batteries are assumed to be deployed in a distributed form. Power producers and storage units invest in capacity as long as the fixed and variable costs can be remunerated according to a perfect market assumption.

Case studies are carried out considering a scenario with 80% potential RES injection measured as fraction of total demand. Within the outlined assumptions, the following scenarios have been considered:

1) All technologies available, carbon emissions price.
2) No PHES available, carbon emissions price.
3) Limited PHES available, carbon emissions price.
4) No storage available, carbon emissions price.
5) All technologies available, carbon emissions quota, including a sensitivity analysis on the quota level.
6) Limited PHES available and a carbon emissions quota.
7) No PHES available, carbon emissions quota.
8) No storage available, carbon emissions quota.

Case 1 is the base case with all technologies available and a given carbon emissions tax. Different assumptions regarding the availability of energy storage technologies are tested. In cases 3 and 6, the PHES capacity is restricted to a maximum of 20 GW. Further, cases 2 and 7 consider a scenario with zero PHES available. Cases 4 and 8 consider a power system with thermal power producers and RES while no energy storage options are available.

The carbon emissions quota in cases 5 - 8 are set equal to the total carbon emissions calculated in case 1. In addition, a sensitivity analysis on the quota level is carried out using case 5 as the base case.

A. Input Data

1) Thermal and storage: Characteristics of thermal power producers and storage technologies included in the case study are presented in Table I, II, and III. The data obtained in the form of total investment costs have been recalculated to annual costs using an assumed interest rate of 5%. Conversions from NOK to EUR are performed using an assumed exchange rate of 9 NOK/EUR.

TABLE I
Technology characteristics for conventional power producers [6]. Annualized values.

	Nuclear	Hard coal	CCGT	OCGT
Fixed costs [EUR/MW]	313 884	146 660	67 445	51 788
Variable costs [EUR/MWh]	8.22	26.71	46.47	73.37
Technology life [years]	60	25	25	25
Efficiency [%]	34	43	57	33
Emissions [ton/MWh]	0	0.871	0.351	0.606

According to Table II, PHES has zero costs associated with reservoir size since this is assumed to be utilization of existing Norwegian reservoirs. However, there is a limit of 15 TWh reservoir capacity available. The costs related to increased PHES capacity and HVDC connection must be remunerated by the market. PHES reservoir level is set to 7.5 TWh while battery level is set to zero during the first time step. Energy storage is characterized by a round-coupling between the first and the last time step.

Coal and combined-cycle gas turbines (CCGT) with carbon capture and storage (CCS) has been included in the pool of available technologies. Parameters for CCS power plants are presented in Table III. CCS plants are rather expensive and have a lower efficiency compared to conventional power plants, but may become profitable given a high carbon price.

TABLE II
TECHNOLOGY CHARACTERISTICS FOR STORAGE UNITS [5] [7] [8]. ANNUALIZED VALUES.

	PHES	Battery
Fixed costs [EUR/MW]	114 098	25 901
Fixed costs [EUR/MWh]	0	6 475
Cycle efficiency [%]	80	92
Self discharge [%/MWh]	0	0
Maximum Capacity [TWh]	15	-
Technology life [years]	30	10

TABLE III
TECHNOLOGY CHARACTERISTICS FOR POWER PRODUCERS WITH CARBON CAPTURE AND STORAGE [6]. ANNUALIZED VALUES.

	Coal CCS	CCGT CCS
Fixed costs [EUR/MW]	227 382	143 047
Variable costs [EUR/MWh]	73.16	64.13
Technology life [years]	25	25
Efficiency [%]	35	49
Emissions [ton/MWh]	0	0

2) Renewable energy sources: The renewable energy per MW installed RES capacity is a time series of hourly production gathered from [9]. The wind series is a weighted average of onshore (87%) and offshore (13%) according to the e-Highway 2050 scenario for large scale RES [10]. Potential RES production (parameter RES) is set to 0.8, or 80% of total demand.

3) Demand: The source for demand data is the time-series data from ENTSO-E, Vision 4 [11]. The data for Belgium, France, Germany, and the Netherlands are aggregated to represent the total demand for this area.

B. Results

This section presents the results of the case study. Analyses are initially performed with a fixed emission cost. Thereafter, a quota based on the initial results has been applied and assumptions regarding the availability of energy storage are tested. Last, a sensitivity analysis on the quota level is conducted.

1) Fixed carbon tax: Cases 1 - 4 include a fixed carbon emission tax of 76 EUR/ton according to ENTSO-E Vision 4 [11] with the amount of carbon emissions as a result of the the fixed carbon price. Main results from these cases are presented in Table IV. The lowest level of carbon emissions occur in case 1, when all technologies are fully available. This case has a significant amount of PHES, indicating that a future power system with high levels of RES and carbon taxes offer abundant business opportunities for PHES plants. However, the competitiveness of PHES in the given market setting resulted in zero installed battery capacity even with the optimistic battery cost data used in these analyses.

TABLE IV
COMPARISON OF RESULTS WITH AN EMISSION TAX OF 76 EUR/TON

Case	Case 1	Case 2	Case 3	Case 4
Storage	All	No PHES	PHES limit	No storage
Wind[MW]	372 618	336 671	344 839	365 637
Solar[MW]	146 091	246 380	223 594	165 568
Thermal[MW]	109 953	155 185	143 152	169 964
Battery[MW]	0	35 641	23 293	0
PHES[MW]	59 811	0	20 000	0
RES curt.[GWh]	45 021	120 035	84 654	157 927
Emissions[kton]	32 335	45 325	42 249	57 098
Tax[EUR/ton]	76	76	76	76

PHES has significant long term load shifting capability due to the high energy content. A case with zero PHES available was conducted in case 2 and more than twice the amount of the curtailed RES production and a sharp increase in carbon emissions is the result when comparing case 2 against case 1, despite the increase in battery capacity. A significant amount of battery capacity is installed in case 2 since it is the only energy storage available. There is a shift from wind power towards solar power in case 2 due to the change of energy storage, which suggests that batteries are suitable to facilitate high levels of solar power.

Further, it may be argued that the high amount of Norwegian PHES in case 1 (about 60 GW) is unrealistic, at least in the near term, when compared to current generation and transmission capacity between Norway and the northern Europe. Therefore, a case with limited PHES of 20 GW has been computed in case 3. Given the limited amount of PHES available, batteries become competitive and the mix of energy storage technologies change the share of renewable energy towards more solar and less wind generation capacity. The increase in solar production and decrease in wind power production means an increase in total RES capacity because of a lower capacity factor for solar power.

All forms of energy storage have been omitted in case 4 which has the highest carbon emissions. Due to the unavailability of storage options, this is also the case with the most RES curtailment. Case 4 also has the highest level of thermal generation capacity because more thermal back-up capacity is needed when storage is not available for load-shifting purposes.

Thus, there is a business case for energy storage because high shares of RES means that there will be high amounts of excess production available at low or zero market prices. In essence, these findings suggest that energy storage will be able to pay for themselves by price arbitrage in a scenario with high levels of RES. The increase in total capacity in cases 2 and 3 compared to cases 1 and 4 originate from the shift towards solar power with a lower output per installed MW relative to wind. This occurs as the RES limit is on total potential production which allows more total capacity if solar power increase and wind power decrease.

The produced energy with an emission tax is presented in Fig. 2. The cases with energy storage show that a higher amount of produced energy is needed, which may seem counter intuitive. However, the explanation of this is that RES and thermal plants only produce at above zero prices and the amount of curtailed RES generation is not included in the figure. Due to the charge/discharge cycle of energy storage, some energy is inevitably lost, but production curtailment is reduced due to charging of the storage during periods with excess production.

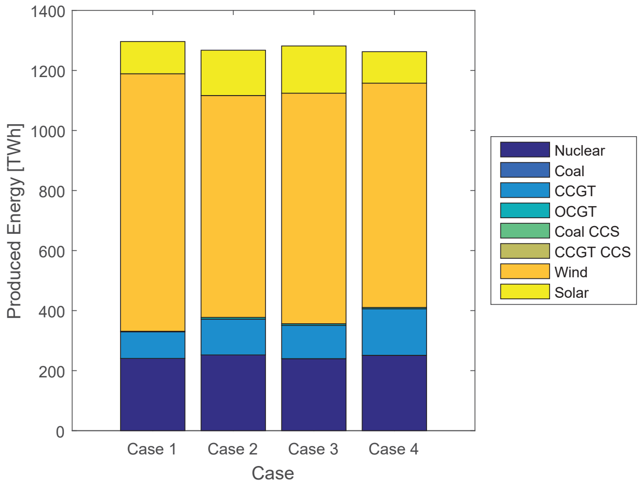

Fig. 2. Production mix with an emission tax of 76 EUR/ton

2) Fixed emissions: Total carbon emissions from case 1 is used as a maximum amount of carbon emissions in case 5 and the required carbon emissions cost is calculated. The resulting tax in case 5 is identical to the fixed tax in case 1. While this is as expected, it nonetheless provide an illustration that setting a tax and let the market work out the emission level or vice versa can have the same effect. However, a policy with fixed carbon emissions cost give uncertainty regarding the carbon emissions level and a policy with a fixed carbon emissions level can lead to unexpected carbon emissions prices.

Table V provide results from case studies with the fixed emission level of 32 million tonnes obtained from case 1. The tax required to enforce the given carbon emissions target change according to the availability of storage technologies. The cases with limited storage require significant tax increases to obtain an equilibrium with the same total carbon emissions as in case 5.

TABLE V
FIXED CARBON EMISSIONS QUOTA

Case Storage	Case 5 All	Case 6 Limited PHES	Case 7 No PHES	Case 8 No storage
Wind[MW]	372 618	345 922	332 852	372 495
Solar[MW]	146 091	220 570	257 036	146 435
Thermal[MW]	109 953	139 318	153 426	169 546
Battery[MW]	0	24 224	40 964	0
PHES[MW]	59 811	20 000	0	0
RES curt.[GWh]	45 021	84 178	116 394	159 666
Emissions[kton]	32 335	32 335	32 335	32 335
Tax[EUR/ton]	76	92	115	126

Fig. 3 illustrate how the capacity mix change depending on the availability of energy storage. Removing storage options means that more thermal power is required to ensure generation adequacy. However, to avoid the carbon emissions increase with a fixed tax as discussed in the previous section, the tax must be increased to enforce the quota. The effect of a tax increase is to reduce the profitability of high carbon emission intensity thermal power producers so that other technologies with lower emission intensity becomes more competitive.

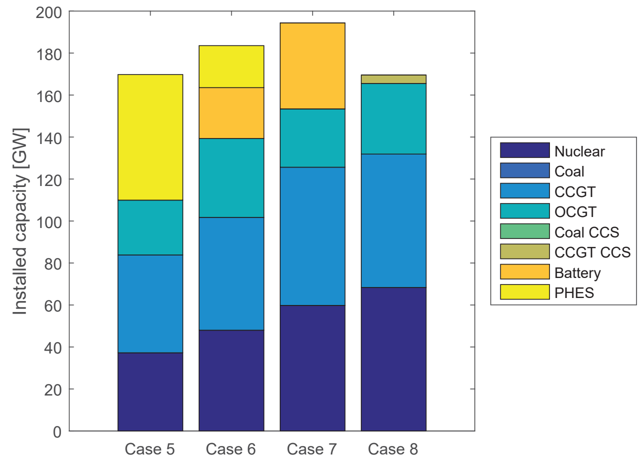

Fig. 3. Capacity mix with an emission quota of 32 Mton

An increased emission tax makes the base load unit, nuclear power, more competitive relative to gas power plants. CCS plants are more expensive to build and operate relative to conventional power plants. Case 8, without any available energy storage capacity, is the only case where CCS capacity can be remunerated due to a carbon price of 126 EUR/ton, approaching the IEA 2040 assumption for the 450 scenario [12]. The CCS capacity that is invested in is a small amount of CCGT with CCS.

3) Sensitivity analysis of emission level: The analyses in this section are performed with no limitations on the availability of energy storage. Case 5 from the previous section is used at the base case and the amount of total carbon emissions permitted is varied between -20% to +20% relative to case 5. In Table VI, the carbon emissions tax change significantly depending on the quota level. A higher quota means that carbon emitting power producers become relatively more competitive due to the lower carbon emissions cost. Increased competitiveness of CCGT with a higher quota level, at the expense of nuclear power, is illustrated in Fig. 4.

TABLE VI
SENSITIVITY ANALYSIS ON CARBON EMISSIONS QUOTA

Emissions quota	-20%	-10%	Case 5	+10%	+20%
Wind[MW]	377 544	372 175	372 618	372 703	358 369
Solar[MW]	132 347	147 326	146 091	145 854	185 845
Thermal[MW]	108 424	109 983	109 953	109 685	110 980
Battery[MW]	0	0	0	0	654
PHES[MW]	60 975	59 793	59 811	60 076	59 795
RES curt.[GWh]	45 584	44 890	45 021	44 776	42 516
Emissions[kton]	25 868	29 102	32 335	35 569	38 802
Tax[EUR/ton]	110	81	76	71	34
Tax change[%]	+45	+7	0	-7	-55

RES curtailment varies depending on the emission level. This is mainly due to two reasons. First, a change in emissions quota alters the price structure of carbon emitting thermal power plants due to the emission tax, which in turn lead to different market prices and a change in the optimal RES mix. Second, the profitability of energy storage varies while RES curtailment depend on available energy storage capacity to store excess RES production.

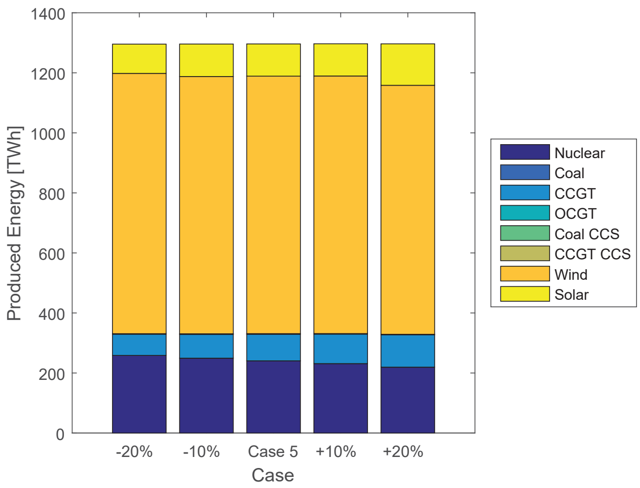

Fig. 4. Production sensitivity to carbon emissions level

Installed capacities for thermal power producers and storage units are presented in Fig. 5. The storage capacity that is invested in is mainly PHES, except for a small amount of battery capacity in the case with a 20% increase in the carbon emissions quota. This suggest that the profitability of PHES is not very sensitive to the carbon emissions market.

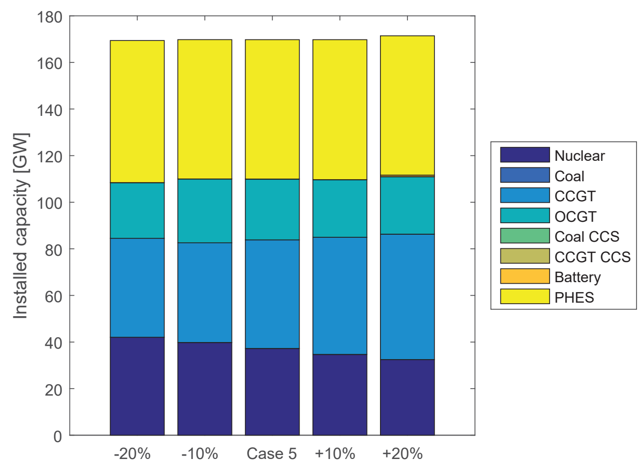

Fig. 5. Capacity sensitivity to carbon emissions level

IV. Conclusions

Case studies on a power system with a carbon emissions tax and subsequent studies with a carbon emissions quota have been performed. The objective is to assess how the capacities and dispatch change with the availability of energy storage and the sensitivity to changes in the carbon emissions quota level.

Energy storage technologies enable large emission reductions because low-cost energy may be stored for later dispatch. As a result of the expected transition of the power system generation portfolio, a rather large amount of energy storage is warranted. If energy storage is restricted, a significant amount of thermal generation capacity is required to serve as back-up capacity.

The carbon price required to enforce a given emission target can be reduced by increased investments in energy storage. Further, while CCS technology is expensive, CCGT plants with CCS technology may become competitive due to carbon restrictions.

Relative competitiveness between thermal generation units is affected by the carbon emissions quota level through a carbon emissions tax. The carbon emissions market conditions can greatly influence the profitability of carbon intensive technologies and should be taken into consideration by market stakeholders.

Further work could include more elaborate studies to determine the path to a power system with reduced carbon emissions and further assessment regarding the profitability of CCS power plants.

References

[1] European Commission, "Energy Roadmap 2050," 2012, accessed: 16-01-2017. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf

[2] Q. Chen, C. Kang, Q. Xia, and D. S. Kirschen, "Optimal Flexible Operation of a CO_2 Capture Power Plant in a Combined Energy and Carbon Emission Market," *IEEE Transactions on Power Systems*, 2012.

[3] Z. Ji, C. Kang, Q. Chen, Q. Xia, C. Jiang, Z. Chen, and J. Xin, "Low-Carbon Power System Dispatch Incorporating Carbon Capture Power Plants," *IEEE Transactions on Power Systems*, 2013.

[4] European Commission, "2050 low-carbon economy," http://ec.europa.eu/clima/policies/strategies/2050_en, accessed: 16-01-2017.

[5] M. Askeland, "Analysis of the Profitability of Energy Storage for RES in an Equilibrium Model of the Power market," Master's thesis, NTNU, 2016. [Online]. Available: http://hdl.handle.net/11250/2405534

[6] M. Sidelnikova, D. E. Weir, L. H. Groth, K. Nybakke, K. E. Stensby, B. Langseth, J. E. Fonneløp, O. Isachsen, I. Haukeli, S.-L. Paulen, I. Magnussen, L. I. Husabø, T. Ericson, and T. H. Qureishy, "Kostnader i energisektoren," 2015. [Online]. Available: http://publikasjoner.nve.no/rapport/2015/rapport2015_02a.pdf

[7] M. Korpås and O. Wolfgang, "Norwegian pumped hydro for providing peaking power in a low-carbon european power market - cost comparison against ocgt anc ccgt," in *12th International Conference on the European Energy Market (EEM)*, 2015.

[8] H. L. Ferreira, R. Garde, G. Fulli, W. Kling, and J. P. Lopes, "Characterisation of Electrical Energy Storage Technologies," *Energy*, vol. 53, pp. 288–298, 2013.

[9] S. Jaehnert and G. Doorman, "Analyzing the Generation Adequacy in Power Markets with Renewable Energy Sources," in *11th International Conference on the European Energy Market (EEM14)*, 2014.

[10] "e-Highway database per country," accessed 17-01-2017. [Online]. Available: http://www.e-highway2050.eu/fileadmin/documents/Results/e-Highway_database_per_country-08022016.xlsx

[11] ENTSO-E, "Ten-year network development plan 2016 projects and scenario data," accessed: 10-24-2016. [Online]. Available: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/rgips/TYNDP2016%20market%20modelling%20data.xlsx

[12] International Energy Agency, "World energy outlook," 2015.