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Challenges to integrate CCS into low carbon electricity markets

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Abstract

This paper discusses challenges for integration of CCS into competitive electricity markets by using the European electricity supply system as an example. The work is based on techno-economic modelling of the European electricity generation sector up to Year 2050, assuming a tightening cap on CO2 emissions down to almost no emissions by 2050. It is concluded that natural gas fired conventional power plants is likely to be a serious competitor to coal CCS in the short to medium term providing large emission reduction by fuel shifting from existing coal power plants to new high efficiency gas fired plants. This can be a barrier for early deployment of CCS without additional support. It is also concluded that for regions with large amount of intermittent electricity generation, short term balance in generation will impose challenges to handle CCS plants in relation to load following requirements. Yet, there are regions with good availability of coal combined with unfavorable conditions for wind power, for which CCS can operate in typical base load.

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Keywords: CCS, flexibility, operation, integration, variable generation

1. Introduction

The long term goal of the EU energy and climate policy is to reduce CO_2 emissions to comply with a 2ºC warming target. In line with this, the European Commission (EC) has presented an "Energy roadmap 2050" [1], which presumably will found the basis for targets and goals for the European energy system to 2050. The scenarios presented in the Energy roadmap communication depicts different ways to fulfil the EU´s decarburization objective, i.e., greenhouse gas emissions from the energy system should be reduced by at least 80% by 2050 relative 1990

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emission levels. Moreover, the roadmap indicate large CO_2 emission cuts within the electricity supply system, i.e., between 93-99% relative to the 1990 emissions, which obviously calls for competitive new power technology with more or less zero CO_2 emissions. In this, CCS technologies will play a significant role but the CCS technologies will then be part of a system with large amounts of intermittent and renewable power generation. This imposes challenges for CCS since load following capabilities will be valued higher and the future role and competitiveness of base load plants is thereby unclear. Thus, a future electricity system with large amounts of intermittent electricity generation will obviously put higher requirements on the thermal plants, including plants with CO_2 capture, with respect to their ability to perform stop and start and part load operation.

CCS plants are typically seen as base load plants and it is not obvious how they can be operated with varying load. Yet, there are a number of studies which have investigated different strategies for and characteristics of part load operation of CCS plants [2-11]. These studies focus on the performance of individual plants [4-9] or a small number of plants [10] with respect to their ability to operate in part load. While [4-10] do not give any information on what will the typical requirements on part load operation within an electricity generation system consisting of a portfolio of technologies, [2], [3] and [11] do evaluate a portfolio of technologies in an energy systems analysis but do not include any aspects on regional variations in the electricity generation mix or limitations in transmission capacity between regions in an integrated electricity market such as Europe. In order to investigate how requirements of part load operation vary across regions, the entire electricity generation system must be analyzed over the region of interest with a sufficiently high time resolution with the modeling incorporating a portfolio of technologies. The aim of the work presented in this paper is to take a first step in this direction, modeling pathways for the transformation of the European electricity system. The region consists of EU27, Norway and Switzerland and we discuss requirement on future CCS operation based on results from scenario analyses for the European electricity supply system with the aid of a modelling package consisting of a techno-economic investment model (ELIN) and a dispatch model (EPOD regional) applied to a particular year.

2. Methodology

The ELIN/EPOD modelling package [12, 13, 15] is applied up to the year 2050 under a typical scenario following the EU energy roadmap. Thus, for such a roadmap, the ELIN modelling will yield a system with large amounts of intermittent electricity generation mixed with thermal plants including CCS plants. The system is then further analysed by the EPOD modelling for the system as it looks for a particular year, with respect to the dispatch characteristics of the different generation technologies. Two scenarios are included; a "Climate Market" scenario and a "Regional Policy" scenario. The Climate Market scenario is inspired by the "Reference High GDP" and the "Diversified Supply Technologies" scenarios from the Energy Roadmap communication by the European Commission (EC) [1]. These scenarios combine relatively high economic growth with a policy almost entirely focusing on carbon markets. The Regional Policy scenario includes several policies and targets as well as a cap on CO_2. The Policy scenario is coarsely based on the "High Energy Efficiency" scenario of the EC Energy Roadmap communication [1]. Yet, we assume an even more aggressive end-use efficiency strategy implying slowly declining overall electricity demand post 2030. In both cases, the ELIN modeling basically simulates the EU-ETS system for which the cap of the emission from the electricity generation system of the entire region (EU27+ Norway + Switzerland) is reduced over the period. In the Climate Market scenario, this is the only policy measure after Year 2020 and the cap is reduced over the period to comply with a 93% reduction in emission in Year 2050 relative to the emissions in Year 1990. In addition to the CO_2 cap, the Regional Policy scenario then includes several policies and targets including specific targets for renewable electricity generation (RES-E), demand side efficiency measures as well as a cap on CO_2. The CO_2 cap in the Regional Policy scenario corresponds to a 99% reduction of CO_2 emissions in Year 2050 relative to Year 1990.

The ELIN model (see [12, 13]) is a long-term dynamic optimization model which describes the present generation system derived from the Chalmers power plant database [14] and an extensive basket of new technologies which are to meet the changes in future demand as existing capacity is phased out. The model includes 16 intra-annual time steps (four seasons, weekday/weekend and day/ night) to reflect variations in load, and thus, the model accounts to some extent for the need of power with different characteristics (peak/base-load). In the modeling, the existing capacity may be used until the end of the assumed life time or be prematurely phased-out due to a CO_2 penalty or the relatively lower efficiency compared to that of new plants. This is to account for the turn-over in capital stock of the existing power plant infrastructure, timing of investments and infrastructural implications of technology mixes on a regional level. The short-term dispatch model EPOD is a recently developed model [15] which analyses in detail a specific year based on the capacity (existing and new) obtained in a preceding ELIN model run. The dispatch analyses may be conducted weekly, diurnal or hourly. Findings from the EPOD analyses concerning the feasibility and efficiency of the system are fed back into ELIN in order to improve the setup of that model. Here, a three hour time resolution is applied in the EPOD model.

Included in the ELIN/EPOD package is a regionalization, in which the EU Member States are divided into 50 intra-national regions, composed of a specified set of NUTS2 areas as shown in Figure 1. The regions are defined by major transmission bottlenecks, as seen today and in the near future (i.e. provided cost efficient the ELIN model can invest in additional transmission capacity). Thereby, intra-national as well as international grid issues may be handled. The refined regionalization also provides means to investigate allocation of renewable power, such as wind and solar power, where production is highly dependent on geographical siting.

In this work we exemplify the resulting variability of CCS plants in the year 2050 for the two regions indicated in red in Figure 1; Northern Poland (PL3) and Hungary (HU). The PL3 region is characterized by rather favorable wind conditions, whereas Hungary has unfavorable wind conditions. Yet, Poland, including PL3, has currently little wind power (as has Hungary). Another difference is that the PL3 region has significant transmission capacity to neighboring regions which is not the case for Hungary. To what extent the modeling will invest in new transmission capacity depends on the value of exporting surplus power during high wind production.

Since the aim of this work is to understand the requirements of part load operation of CCS plants in a future electricity system and since the future characteristics of part load capability of CCS plants are not known in detail, we have applied a simplified approach in this work with respect to characterizing flexibility of CCS plants. The above mentioned assessments of operating flexibility of CCS plants given in literature [4-9] indicate that a future CCS plant will have more or less similar part load characteristics as a conventional plant burning the same fuel. In line with this, we have defined the flexibility in operation so that the start-up time is the same as conventional plants without capture and set to 6h and the minimum part load operation is set to 50% for all CCS plants as compared to conventional plants without capture for which minimum load is 35% for coal, 20% for gas and 50% for biomass. We hereby assume that issues such as the rather long start-up time for an Air Separation Unit (ASU) for oxyfuel fired plants is handled by means of buffering possibilities. Since part load operation capabilities will be valued higher in a future system it seems as a fair assumption that the possibilities from the surrounding system to buffer both oxygen and carbon dioxide will be utilized; *cf* [6-8]. The somewhat higher min load of 50% for CCS plants compared to the above values for non-CCS plants, is thus the same as for biomass only plant without CCS. A motivation for applying 50% as minimum level for CCS plants is that at the end of the period investigated there is basically room only for CCS with biomass co-firing for off-setting an assumed capture rate of 90%, which should have a somewhat less good part load performance than coal-only CCS. Part load operation in the modeling is also associated with a reduced efficiency (reduced to 50% of the efficiency at rated power). Since the modeling does not resolve individual plants but aggregates of plant types, the degree of part load is expressed by the fraction of plants which operate at 50% part load. In the modeling of this work, it is assumed that the CCS plant can reach full load from 50% load from one time step to the next. This should be a fair limitation when investigating the ability to balancing variations in the context of a large region with large amount of wind power. There may of course be more local effects which would require a higher time resolution for a sufficiently detailed analysis and which could then resolve and investigate possibly benefits for the higher ramp rates reported in [6-7].

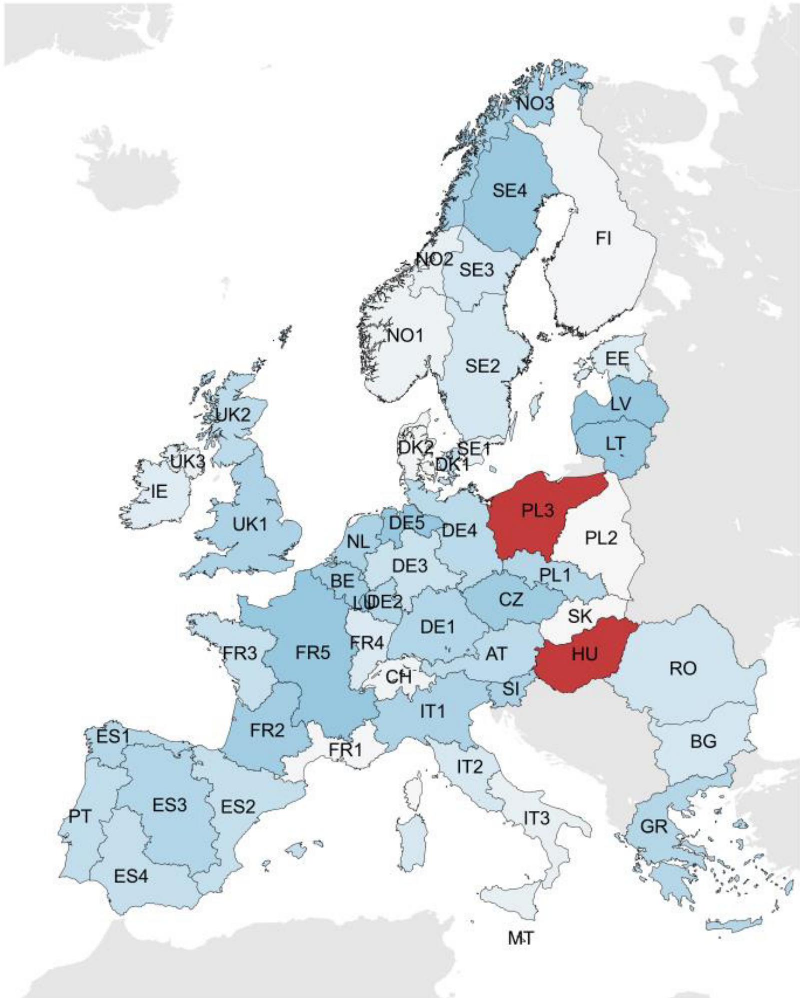


Figure 1. The regions applied in the modeling of this work. The two regions (PL3 and HU) used to exemplify the requirements on operating flexibility is indicated in red.

3. Results

Figure 2 shows the development of the electricity generation system as obtained from the ELIN model in the two scenarios; the Climate Market (CM) and the Regional Policy (RP) scenario. As can be seen both scenarios result in a broad technology portfolio, including CCS as well as large quantities of renewables, mostly in the form of biomass and wind power. The lighter colored fields in the plots represent the existing generation capacity which is phased out over the period. Yet, the long lived nature of the power plants can be seen from that half through the period studied (in Year 2030), around half of the existing generation capacity is still in operation in both scenarios. It is clear that in both scenarios, CCS technologies play a significant role to reach more or less a carbon neutral electricity supply system by 2050, as described in the EU Energy roadmap 2050, especially if we fail in curbing growth in electricity demand (CM scenario). Towards the end of the period (near Year 2050), CCS with biomass co-firing is required in both scenarios. This, in order to off-set that the capture in CCS plants is assumed to be 90% and, therefore, in the end of the period there is too little room for emitting this slip from fossil fuelled CCS plants, especially in the RP scenario with its 99% reduction in CO_2 emissions. The results in Figure 2 also indicate that natural gas fired conventional power plants are likely to be a serious competitor to coal CCS in the short to medium term providing large emission reduction by fuel shifting from existing coal power plants to new high efficiency gas fired plants. In the "ideal perfect-foresight world" represented by the modeling results, natural gas instead act as a bridging technology to a near zero emitting electricity generation system in Year 2050. In order for this to happen in the real world, a long term climate mitigation policy is required, such as could be achieved with a well-functioning EU-ETS system. This, however, would most likely require additional support to stimulate large-scale demonstration and implementation of CCS before it can compete with natural gas firing (CCGTs without capture). It should be noted that, at present (Year 2014), the low EU-ETS allowance prices together with reduced coal prices because of changes on the global gas market have made gas less profitable in Europe.

The prospects of CCS on a regional level, EU Member State level and within MSs, depend on local conditions in terms of current energy mix, fuel supply chains and distance to suitable CO_2 storage locations. This can be seen from Figure 3 which gives the corresponding technology mix for Poland and Hungary for the two scenarios investigated (CM and RP). A significant difference between the two regions is that in Poland, the relatively favorable wind conditions make wind power a substantial part of the generation portfolio whereas Hungary's generation mix remains basically thermally dominated throughout the period. Only in the RP scenario there is some wind power in the end of the period. In both regions, CCS becomes a cost efficient mitigation technology from around Year 2040 in Hungary for both scenarios and in Poland in case of the RP scenario. For the CM scenario in Poland, CCS is introduced already around 2025 to meet the demand for power. Or in other words, the conditions for renewable power and trading with neighboring regions in Poland cannot meet all demand at a cost lower than CCS in the CM scenario.

As indicated previously, the PL and HU in Figure 3 were selected as examples since they represent different conditions with respect to amount of variable generation and transmission capacity to neighboring regions. Thus, in spite of the tight emission cap in the end of the period for the entire region investigated, the combination of relatively unfavorable wind conditions, limited profitability of investing in transmission capacity to neighboring regions makes the HU system dominated by thermal generation, especially in the CM scenario.

Figure 4 shows results from the EPOD model, i.e. the hourly variations (3 hour resolution) in the electricity generation together with the load (black solid curve), for the HU and Northern Poland (PL3) regions in case of the CM scenario. Thus, as opposed to Figure 3, which gives the technology mix for Poland as a whole, Figure 4 gives the generation only for PL3 (*cf.* Figure 1). This will further accentuate the effect of large amount of intermittent generation, since this is mainly located in PL3, where wind conditions are favorable. This means that generation exceeding the load is being exported to neighboring regions and that import occurs when load exceeds generation within the region. In line with the above discussions there is a significant difference in the generation pattern between the two regions. In Hungary (Figure 4a), the system in Year 2050 resembles todays typical continental system with the bulk of the generation being from thermal plants with a relatively large number of Full Load Hours (FLH). As seen in Figure 4a, for the three weeks exemplified there is only one occasion when the load of the CCS plants deviates from full load. This is in contrast to PL3 shown in Figure 4b where large variations in wind power and trading with neighboring regions makes it difficult for CCS to compete as base load with the renewable generation and import export to cover corresponding deficit and excess of generation within the region. Instead, CCS is operated as flexible operation. Thus, the most cost efficient is to also regulate CCS, which can be seen from the deviations to part load in Figure 4b.

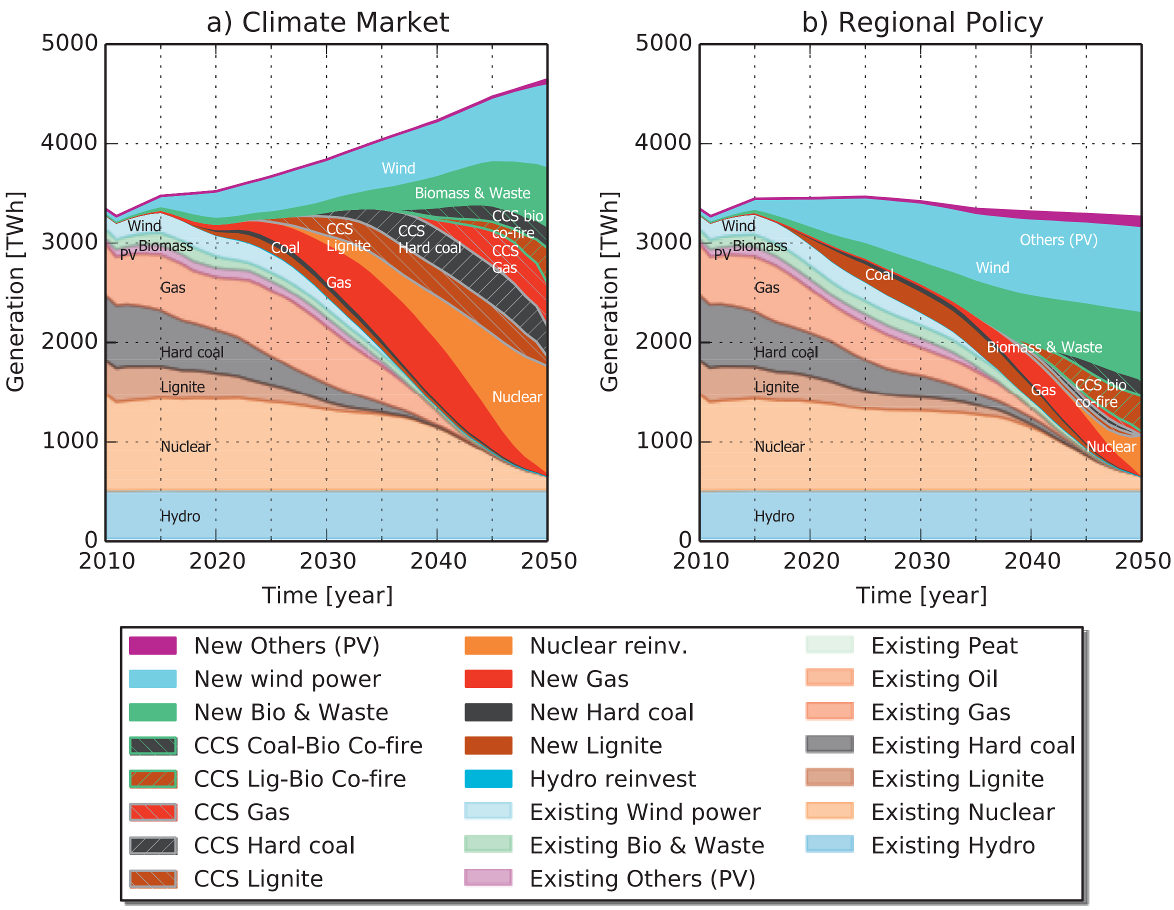


Figure 2. The resulting technology mix from the ELIN modeling over the period 2010 to 2050 for the Climate Market (left panel) and Regional Policy (right panel) scenarios. EU27+Norway + Switzerland.

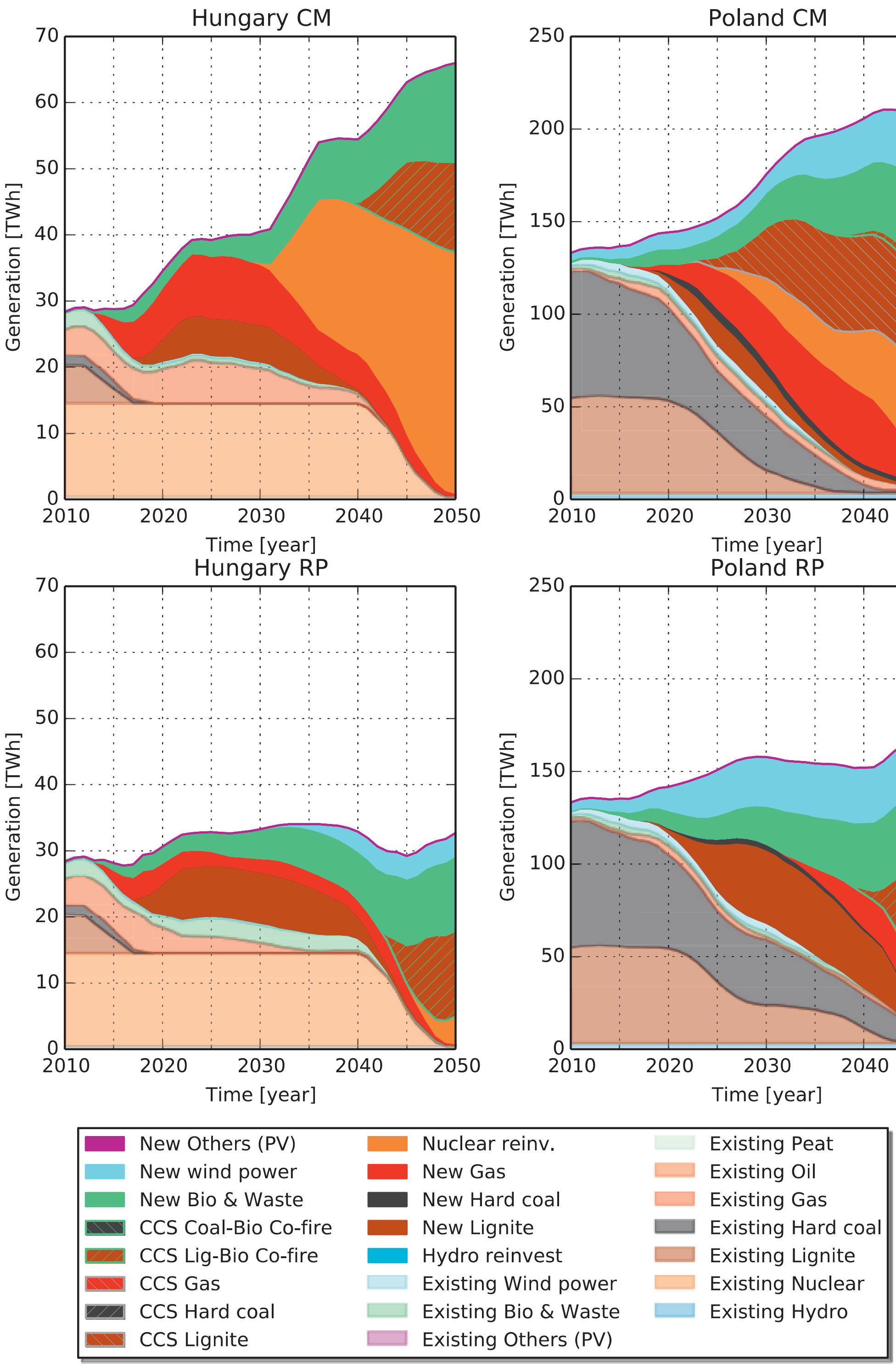
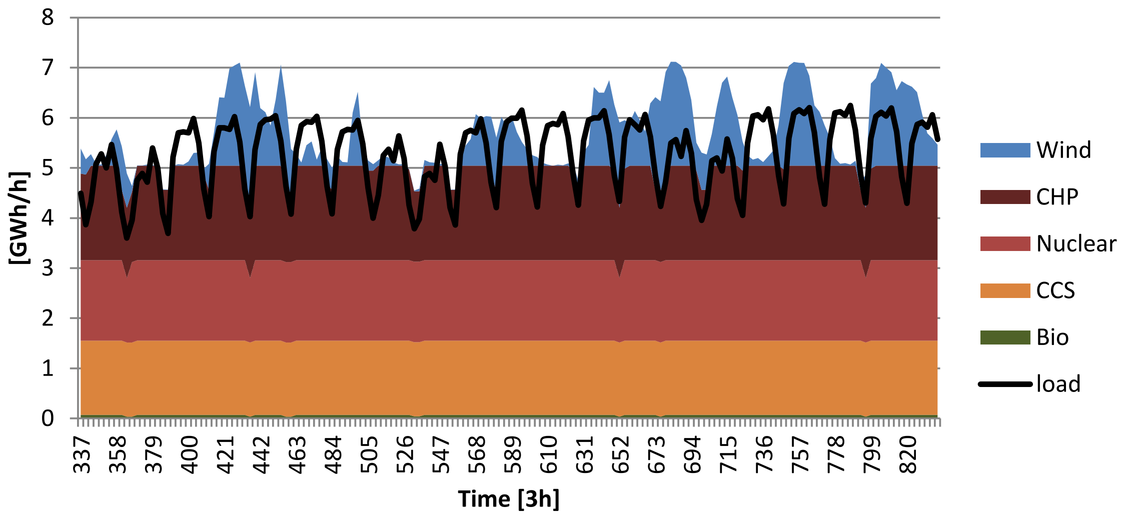
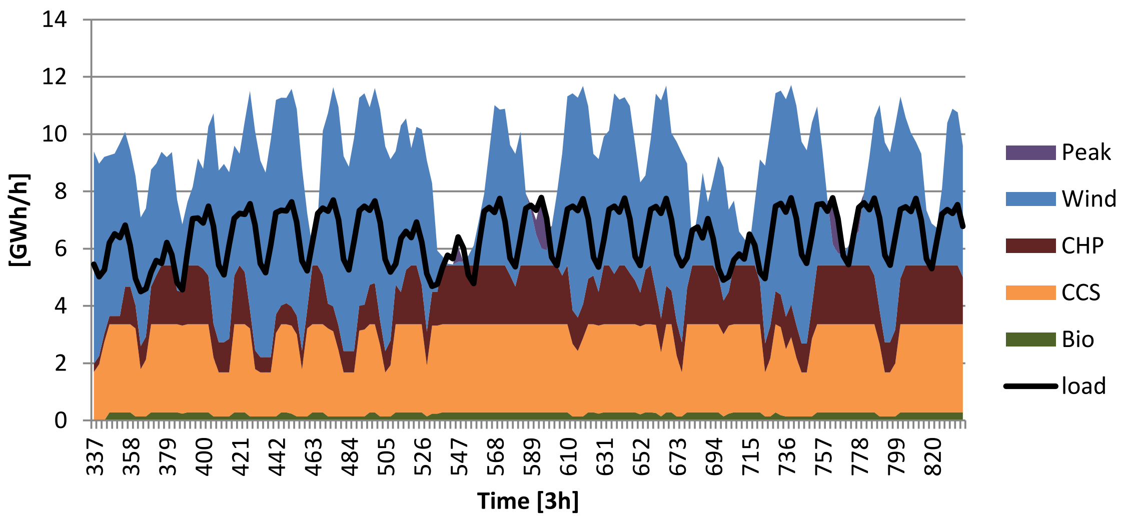


Figure 3. The resulting technology mix from the ELIN modeling over the period 2010 to 2050 for the Climate Market (upper panels) and Regional Policy (lower panels) scenarios for Hungary (left panels) and Poland (right panels).



a.



b.

Figure 4. Example of generation pattern (3 hour resolution) and domestic load variations for HU (a.) and PL3 (b) during three weeks in autumn for year 2050 in the Climate Market scenario.

4. Conclusions

A techno-economic modeling study to assess challenges to integrate CCS into a low carbon electricity market in Europe is performed. The focus is on the transition of the system up to Year 2050. We conclude that that natural gas fired conventional power plants are likely to be serious competitors to coal CCS in the short to medium term providing large emission reduction by fuel shifting from existing coal power plants to new high efficiency gas fired plants. This can be a barrier for early deployment of CCS resulting in a lock-in in a natural gas dominated system.

Yet, the model results correspond to a long-term climate mitigation policy such as could be achieved with a well-functioning EU-ETS system and with such policy measure, natural gas can act as a bridge to an almost zero emitting electricity generation system by Year 2050. This, however, requires additional support to stimulate large-scale demonstration and implementation of CCS before it can compete with natural gas firing (CCGTs without capture). It is also concluded that for regions with large amount of intermittent electricity generation (here exemplified with Northern Poland), short term balance in generation will impose challenges to handle CCS plants in relation to load following requirements. Yet, there are regions with unfavorable conditions for wind power for which CCS can operate in typical base load (here exemplified with Hungary).

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