Impact of Carbon Price on Renewable Energy Using Power Market System

Xiangping Hu[1], Xiaomei Cheng[2], and Xinlu Qiu[3]

Abstract. Reducing anthropogenic greenhouse gas emissions is a critical element to keep global warming below 2 °C. In terms of the IEA report, the largest sources of emission in 2016, which approaches to 42% of global total, is generated by power sector and heat sector. This indicates that reducing the emission in the power sector can play a crucial role to limit global warming. Large shares of low-carbon generators such as renewables, power plants with carbon capture and storage and implementing a sustainable environmental tax or carbon price are the possible approaches to reduce the emissions from the power sector. The paper investigates how carbon prices affect the Northern European power system. The power system model is net transfer capacity-based model which aims to minimize economic performance, such as operational cost and environmental cost, with the common power system constraints and large expansions of sustainable energy development, i.e., solar and wind energy. The carbon prices are based on scenarios of the Shared Socioeconomic Pathways (SSPs) which aims to limit global warming to below 2°C with a probability greater than 66%. Four scenarios are conducted based on SSPs carbon prices. Results show that the carbon prices have a great impact on the economic performance of the power system, i.e., the higher carbon price, the higher power prices. Increasing carbon prices result in decreasing of coal production including hard coal and lignite coal production but increasing the gas production. This is due to different fuel carbon prices. Furthermore, renewable energy such as wind production continues to increase. This implies a positive relationship between renewable energy and carbon prices, such as the higher the carbon prices, the higher renewable energy production.

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[1] Xiangping Hu (🖂)
Industrial Ecology Programme, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
Xiangping.Hu@ntnu.no
[2] Xiaomei Chen (🖂)
Department of Electric Power Engineering, Norwegian University of Science and Technology, Trondheim, Norway
Xiaomei.Chen@ntnu.no
[3] Xinlu Qiu
Department of Industrial Economics and Technology, Norwegian University of Science and Technology, Trondheim, Norway
Xinlu.Qiu@ntnu.no

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1 Introduction

The ambition of the Paris Agreement on climate change is to keep a global temperature rise this century below 2°C compared to pre-industrial level, which changes the path of the energy sector development. In 2016, 42% of global CO2 was from the electricity and heat generation [1]. Therefore, this implies that the power sectors have great potential for limiting global warming to no more than 2°C. Many approaches, such as increasing the share of renewable energy and introduce the carbon prices into power sectors, have been developed to reduce the emission from power sectors. Introducing the carbon price into the energy sector is one of the important approaches to alleviate the carbon emission, and hence achieving decarbonization goal [2, 3]. To achieve low emissions scenarios, an implicit carbon shadow price is usually assumed, and this price can also be used as policy instruments [3]. The carbon prices vary with different scenarios for climate change mitigation and adaptation, especially in the long run [3-6].

The Shared Socioeconomic Pathways (SSPs) are established by the scientific community and are part of a new scenario framework [7]. These pathways describe five different development trends in future by considering different scenarios for climate change projections, challenges for mitigation and adaptation to climate change, socioeconomic conditions and policies [7-10], and they are used to facilitate a harmonized framework for integrated analysis for interdisciplinary research of climate impact, and the aim of these pathways is to investigate future changes in different sectors or countries [7, 11].

In this paper, we investigate the impact of carbon prices on the environment and sustainable energy development based on the Northern European power system. The power system model used in this paper is the net transfer capacity-based model (NTC). These carbon prices are based on different pathways in the SSPs framework. Scenarios with possibility to achieve the 2°C target are considered, and therefore, only four scenarios, i.e., SSP1, SSP2, SSP2, and SSP5, with different carbon prices are used. The rest of the paper is organized as follows. Section 2 introduces the data and methodology, followed by results and discussions in Section 3. Conclusions in Section 4 ends the paper.

2 Data and Methodology

2.1 Power system modeling

The power system model is used to simulate the Northern European power grid for six countries. The countries include Norway, Sweden, Finland, Denmark, Germany, and Netherland. The objective of the model is to minimize the operating cost and environmental cost to confirm the hourly energy balance, transfer capacity limits and operational security standards [12]. Fundamental input parameters for power plants, i.e., fixed cost, marginal cost, start-up cost, transmission capacity limitations and so on, are obtained from [13].

The production capacity, demand and transmission constraints in the state of 2010 are used as the initial conditions for simulation in our model. The last point of the previous year's hydro reservoir level is used as the initial condition of the next year's hydro reservoir level. Environmental costs for thermal units are equal to the environmental tax multiplying by the total amount of emissions within the planning periods. The environmental variables, i.e., emission factor, energy efficiencies, and energy conversion factors, originates from the International Energy Agency (IEA) [14]. The main outputs for the model are the spot power prices, mixed production and the amount of carbon emissions. The detailed desperation of the numerical model can be found in [2] and the optimization is conducted using GAMS [15].

2.2 Carbon price and scenarios design

For the sake of generality, the environmental tax mentioned in the previous paragraph is the amount that must be paid for the right to emit one ton of carbon dioxide into the atmosphere. The main target for these carbon prices is to reduce the amount of carbon emission, and further reflects the carbon price's influence on the energy system. The carbon prices used in this work are abstracted within the Shared Socioeconomic Pathways (SSPs) framework [3, 7, 16]. With the same target as the carbon price in the energy system, i.e., reducing the carbon emission amount, the other meaning of the carbon prices under the SSPs framework is to explain the carbon prices' socioeconomic impact, not only the impact on the energy system. There are five different carbon prices within the SSPs framework [7, 16-21]. However, only four types of carbon prices are examined, i.e., SSP1, SSP2, SSP4, and SSP5, since it is not possible to achieve the 2°**C** target under SSP3 [3]. The carbon prices of four scenarios until the year 2050 are shown in Figure 1.

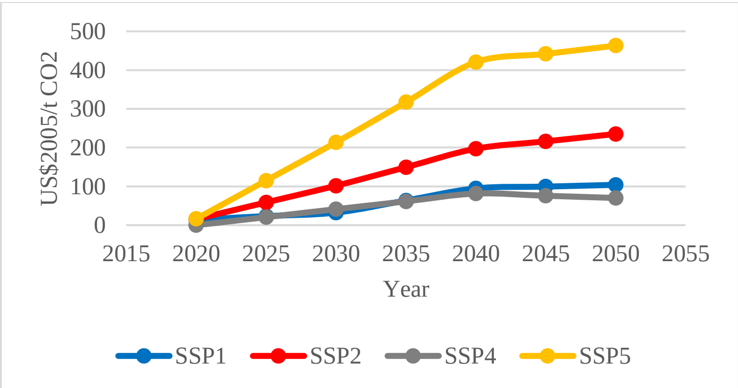

Fig. 1 Carbon prices under SSP1, SSP2, SSP4, and SSP4 for achieving 2°**C** target

3 Results and Discussions

In this section, we investigate these four scenarios and analyze the results in terms of economic and environmental perspectives. Figure 2 shows the annual power prices which is equal to average all countries' prices by year, together with the carbon prices for each scenario. It can be observed that power prices are increased with the rise in carbon prices. This reflects that one of the carbon prices' key role in economic performance in the power system is to regulate power price.

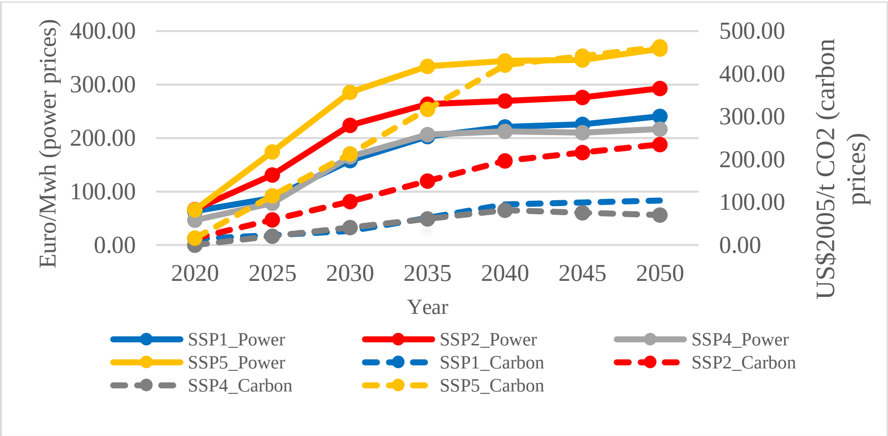

Fig. 2 Annual power prices and carbon prices for each scenario: The annual power prices are given in solid lines with values shown in the left y-axis, and the carbon prices are shown in dashed lines with values shown in the right y-axis.

Figure 3 illustrates the energy mix for each scenario. We can observe that the variations are primarily with gas and coal. The gas production is increased with the rise in the carbon prices, while the coal production including hard coal and lignite coal is decreased. The reason is that with the increasing carbon prices over time, the gas power with low carbon prices is increased to replace power production with high carbon prices, such as hard coal and lignite coal. The wind power continues to increase due to the cheaper power prices. The hydropower production is stable due to the same reservoir level for each year. The reservoir level assumptions for future years could be an interesting topic to be investigated for future study.

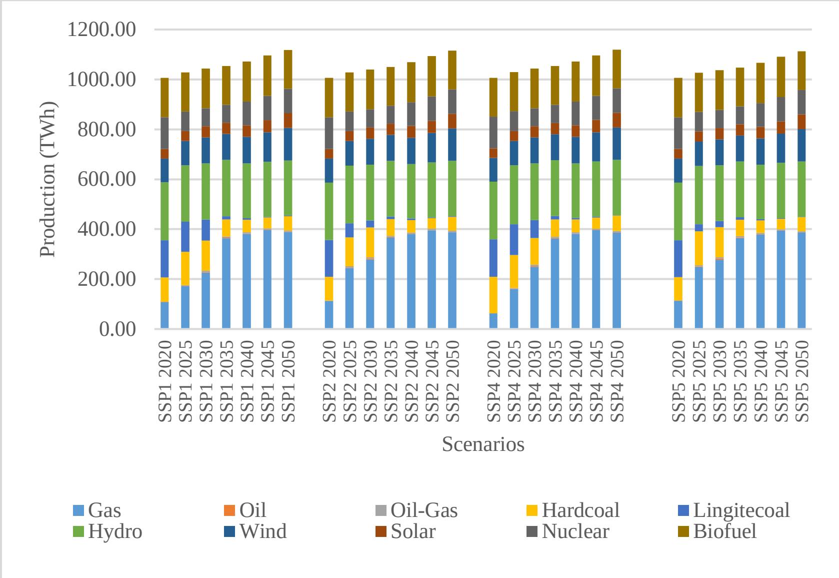

Fig. 3 The energy mix for each SSP scenario

The environmental impact, i.e., the total amount of carbon emission, is shown in Figure 4. From this figure, we can notice that before the year 2030, the highest carbon prices scenario, i.e., SSP5, has the lowest total amount of carbon emission, which is opposite to the lower carbon prices scenario, i.e., SSP1. This implies that the carbon prices before the year 2030 have a positive impact on the total amount of carbon emission. However, the total amount of carbon emission converges to the same amount around 220Mton. This indicates that carbon prices have limited impacts on the total amount of carbon emission in the long-term. This result illustrates that further increasing carbon prices might not have any impacts or may only have a few influences on carbon emission from a long-term perspective.

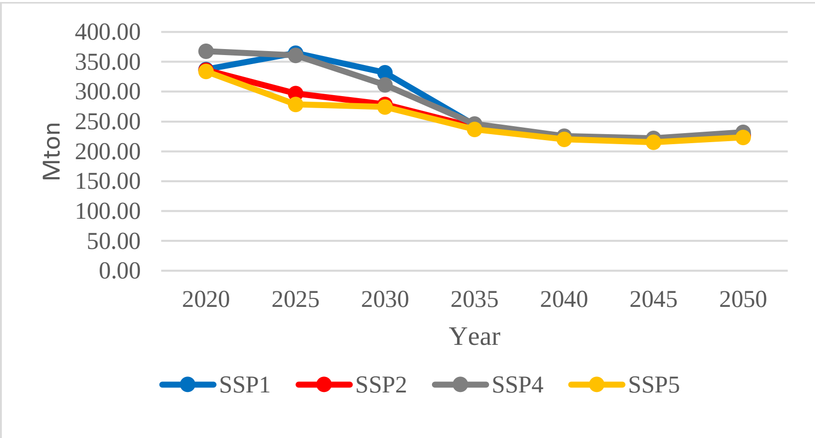

Fig. 4 Total amount of emission for each SSP scenario

4 Conclusions and discussion

In this paper, the environmental impact of carbon prices based on SSPs Scenarios on the Northern European power system is investigated. Four scenarios are conducted. The fact that the carbon prices play an important role in the power prices is illustrated, such as the higher carbon prices, the higher power prices. Within the increasing carbon prices framework, coal production including hard coal and lignite coal is decreased, which is opposite to the gas production. This could be explained by the low gas carbon prices and high coal carbon prices. In addition, renewable production, for instance, wind power production continues to increase as carbon price rises. Furthermore, our simulation results also illustrate that further increasing carbon prices might have few influences on carbon emission in long-term. There is a potential limitation in our simulation that the reservoir level is similar for each year, which leads to stable hydropower production. This could be an interesting topic for further study.

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