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The effect of EU ETS allowances on electricity prices

How do emission allowances impact electricity prices in Finland during the IV phase of the ETS?

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TIIVISTELMÄ:
Tämän pro gradu -tutkielman tarkoituksena on analysoida, miten päästöoikeudet vaikuttavat sähkön hintoihin Suomessa Euroopan unionin päästökauppajärjestelmän neljännen vaiheen aikana. Aihe on erittäin ajankohtainen, sillä päästökauppajärjestelmä on keskeisessä asemassa Euroopan unionin ilmastopolitiikassa ja sitä käytetään ilmastonmuutoksen torjunnassa. Lisäksi energiajärjestelmän vakaus ja energiaturvallisuus ovat nousseet yhä tärkeämmiksi aiheiksi Euroopassa erityisesti Venäjän hyökkäyssodan Ukrainaan sekä Lähi-idän nykyisten jännitteiden jälkeen. Tämän tutkielman tutkimushypoteesina on, että päästöoikeuksilla on positiivinen vaikutus Suomen sähköhintoihin. Päästöoikeuksien ja sähköhintojen suhdetta päästökauppajärjestelmän neljännessä vaiheessa on tutkittu melko vähän verrattuna aikaisempiin vaiheisiin erityisesti Suomessa. Tämä tutkielma vastaa osaltaan tähän tutkimusaukkoon. Tutkimusaineisto koostuu päivittäisestä datasta ajanjaksolta 1.1.2021–30.9.2025, joka kattaa Euroopan unionin päästökauppajärjestelmän nykyisen neljännen vaiheen.

Päästöoikeuksien vaikutuksen arvioimiseksi suoritettiin useita lineaarisia regressioanalyysejä, joissa kontrolloitiin samalla muita sähkön hinnanmuodostukseen vaikuttavia tekijöitä, kuten sähköntuotannon energialähteitä, polttoaineiden hintoja, säämuuttujia, sähkön kysyntää, korkotasoja sekä rajat ylittäviä sähkönsiirtoja. Moninkertaisten lineaaristen regressioanalyysien keskeiset tulokset osoittivat, että päästöoikeuksien hintojen vaikutus Suomen sähkön hintoihin oli positiivinen ja tilastollisesti merkitsevä, ja kontrollimuuttujat käyttäytyivät suurilta osin odotetulla tavalla. Tulokset vahvistavat ja tukevat aiempaa kirjallisuutta siitä, että päästöoikeuksien hinnat vaikuttavat sähkön hintoihin positiivisesti ja että kustannusten siirtymisaste vaihtelee 60–100 prosentin välillä. Tutkielman tulokset ja aiempi kirjallisuus ovat merkittäviä, koska ne vaikuttavat niin päätöksentekijöihin, kuluttajiin kuin koko talouteen. Vaikka hiili-intensiivisen sähköntuotannon osuus on hyvin pieni Suomen sähkön kokonaistuotannosta, sillä on silti vaikutusta sähkön hintoihin. Korkeammat sähkön hinnat heikentävät kotitalouksien ostovoimaa, kallistavat yritysten tuotantokustannuksia ja vaikuttavat tätä kautta negatiivisesti koko talouteen. Erityisesti vaikutukset kohdistuvat kotitalouksiin, joiden sähkönkulutus on vähäistä, sillä heidän maksamansa sähkön hinta on korkein. Tulokset viittaavat siihen, että hiili-intensiivisten energialähteiden käytön vähentäminen sähköntuotannossa voisi alentaa sähkön hintoja, parantaa Suomen energiajärjestelmän vakautta ja energiaturvallisuutta sekä edistää Suomen tavoitetta saavuttaa hiilineutraalisuus.

KEYWORDS: EU ETS, electricity prices, emissions, emission allowances, Finland

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ABSTRACT:
The purpose of this master's thesis is to analyse how emission allowances impact electricity prices in Finland during the fourth phase of the European Union Emissions Trading System (EU ETS). The topic is highly relevant, as the emissions trading system plays a central role in the European Union's climate policy and is a key instrument in combating climate change. In addition, the stability of the energy system and energy security have become increasingly important issues in Europe, particularly following Russia's invasion of Ukraine and the current tensions in the Middle East. The research hypothesis of this thesis is that emission allowances have a positive impact on electricity prices in Finland. The relationship between emission allowances and electricity prices during the fourth phase of the emissions trading system has been studied relatively little compared to earlier phases, especially in the Finnish context. This thesis contributes to addressing this research gap. The dataset consists of daily data from the period 1 January 2021 to 30 September 2025, covering the current fourth phase of the EU ETS.

To evaluate the impact of emission allowances, multiple linear regression analyses were conducted, controlling for other factors affecting electricity price formation, such as energy sources used in electricity generation, fuel prices, weather variables, electricity demand, interest rates, and cross-border electricity transmission. The key results of the multiple linear regression analyses indicate that the effect of emission allowance prices on electricity prices in Finland is positive and statistically significant, and the control variables largely behave as expected. The results confirm and support previous literature suggesting that emission allowance prices have a positive effect on electricity prices, with cost pass-through rates ranging between 60% and 100%. The findings of this thesis and the existing literature are significant, as they have implications for policymakers, consumers, and the broader economy. Although the share of carbon-intensive electricity generation is relatively small in Finland's total electricity production, it still affects electricity prices. Higher electricity prices weaken households' purchasing power, increase firms' production costs, and thereby negatively impact the overall economy. The effects impact households with low electricity consumption especially hard, as they face the highest electricity prices. The results suggest that reducing the use of carbon-intensive energy sources in electricity generation could lower electricity prices, improve the stability and energy security of Finland's energy system, and support Finland's goal of achieving carbon neutrality

KEYWORDS: EU ETS, electricity prices, emissions, emission allowances, Finland

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Abbreviations

Carbon border adjustment mechanism ~ CBAM
Carbon dioxide ~ CO2
Cents per kilowatt hour ~ c/kWh
European energy exchange ~ EEX
European Union Emission Trading System ~ EU ETS

European Union Allowance $\sim$ EUA
Gigawatt hour $\sim \mathrm{GWh}$
Marginal Abatement Cost $\sim \mathrm{MAC}$
Marginal Abatement Cost Curves $\sim \mathrm{MACC}$

1 Introduction

The European Union's Emissions Trading Scheme (EU ETS) is a central climate policy tool for reducing greenhouse gas emissions. It incentivizes emissions reductions through a market-based cap-and-trade system. The EU ETS was established in 2005, becoming the first carbon market in the world, and it remains one of the largest. The EU ETS sets a cap on the amount of carbon that industries can emit, and this cap is reduced over time in line with the EU's goal of achieving carbon neutrality by 2050. Companies can choose to either reduce their emissions or buy allowances on the carbon market. Carbon neutrality by 2050 is an ambitious goal that calls for significant changes in energy production. The ETS, as an environmental policy instrument is cost-effective and incentivizes companies to adopt lower-carbon solutions.

The electricity sector is one of the largest contributors of carbon dioxide in Europe, which is why it is integrated into the EU ETS. Given the sector's ever-growing importance, it is essential to understand how the ETS affects electricity prices. However, empirical research on the impact of emission allowances on Finland during the fourth phase remains underrepresented in the literature. Finland's energy mix is diverse, and it has a relatively low reliance on carbon-intensive energy. Therefore, Finland provides an intriguing case for analysing the influence of emission allowances on electricity prices.

This thesis analyses the effects of emission allowances on electricity prices in Finland during the fourth phase of the EU ETS. This topic is relevant because of the urgency of addressing climate change, as well as the growing importance of energy, recently heightened by both the invasion of Ukraine and the current geopolitical tensions in Iran. The results of this research have implications for policymakers, businesses, and consumers, making it a relevant and important topic for academic research. The main hypothesis of this thesis is that emission allowances increase Finnish electricity prices. The second hypothesis is that the level of cost pass-through depends on other factors, including the energy mix, cross-border flows, fuel, and weather variables.

The second chapter provides an overview of the EU ETS; how it got established, how it has developed, and what its goals and effects are on the energy sector in Europe. In addition, the ETS in the Finnish context and Nordic electricity markets are explained. In the third chapter, the theoretical background of the EU ETS is evaluated, and the theories that support the policy instrument. The fourth chapter includes the data and methodologies used in the empirical research, the extraction process of data, and justification for the decisions made regarding the selection of data and methodologies. In the fifth chapter, the results from the empirical research are presented, and in the sixth chapter, those results are interpreted, and policy recommendations are given. The final chapter includes short concluding remarks and recommendations for future academic research relating to this thesis topic.

2 Background of the ETS

This chapter will explain more thoroughly the European Union emission trading system. First, the general history of the European Union emission trading system and its development in Finland are discussed. This will give context on how the emission allowances have developed over time and how different events and policy changes have influenced them. Finally, the Finnish electricity market and Nord Pool are discussed.

2.1 History of EU ETS

The European Union emission trading scheme was established on January 1st, 2005, as the first carbon market in the world (European Commission, 2020). Before this, the EU had already taken initial steps towards an ETS, such as signing the Kyoto Protocol in 1997 (United Nations, 1998), introducing the green paper in 2000, and finally, the EU ETS directive in 2003, which eventually led to the establishment of the emission trading scheme (European Commission, 2020).

Since those first initial steps, the EU ETS has undergone three different phases and is now in its 4th phase. The first phase began in 2005 and lasted until 2007, during which the groundwork for the now well-known emissions trading scheme was laid (European Commission, 2020). The most important accomplishments of this phase were the establishment of a price for carbon, free trade in emissions allowances, and a functional system for monitoring and reporting emissions from EU countries (European Commission, 2020). In general, this was a pilot phase on how this kind of climate policy would function. In the first period, the EU admitted too many emission allowances, causing the price of carbon to plummet to near zero due to the lack of demand compared to supply (Power-Deriva Oy, 2018, p.9).

The second phase (2008-2012) built on the work that was done in the first phase and expanded to new territories. The EU ETS expanded to Iceland, Liechtenstein, and Norway, and the cap on allowances was lowered by 6.5%. Overall, the rules and regulations for producing emissions were made much stricter compared to the pilot phase. (European Commission, 2020). The reduction in emission allowances increased the price of carbon, which at its highest reached 30 €/tCO2. However, due to uncertainty in the European economy and the subsidies given to renewable energy projects, the price of carbon decreased to only 3 €/tCO2 before the end of the second phase. (Power-Deriva, 2018, p.9).

The third phase (2013-2020) was much more radical compared to the previous two phases. Previous national caps on emissions were changed into one common EU-wide cap on carbon emissions. On top of that, many more industries were placed under the EU ETS (European Commission, 2020). The European Commission also mentions transferring from free allocation to auctioning as one of the major changes during this phase. Since 2013, corporations have needed to buy emission rights if they exceeded the intended cap. However, some highly carbon-intensive industries still gained free allowances due to the risk of carbon leakage. The power sector, however, did not gain substantial amounts of free allowances and was expected to buy the right to pollute. This is completely in line with the European Green Deal (European Commission, 2020).

European Union has committed to decrease its carbon emissions by 55% before 2030 and the EU ETS is expected to be a key climate policy to reach this goal cost-efficiently. To achieve this in the fourth phase (2021-2030) the cap and free allocation are being reduced every year in line with the current EU climate policy (European Commission, 2023). The constant reduction of both the carbon cap and free allocation pushes industries and corporations to reduce the use of carbon in their production. This should also increase innovation in low-carbon and renewable technologies. Below there is a figure from Trading Economics (2024) that shows the development of the EU ETS emission allowance prices from 2010 to the present day.

In 2024, there were significant drops in emissions in the power sector, and the use of renewable energy in electricity generation increased (European Commission, n.d.-a). Maritime transport was also added as a part of the EU ETS. By 2027, ETS2 will be launched as a complementary tool focused on buildings and road transport to achieve the ambitious target of carbon neutrality by 2050 (European Commission, n.d.-b). The carbon prices have fallen slightly during this period because of unstable economic outlooks and falling natural gas prices.

Figure 1. Development of the price of emission allowance under the EU ETS (Trading Economics, 2024).

2.2 Finland's electricity market

Finland, as an EU member has been part of the EU ETS from the very beginning; therefore, it has gone through all the different developments of the system. This has certainly had impacts on all carbon-producing Finnish industries, especially the power sector. To understand the relationship between emission allowances and electricity prices in Finland, it is necessary to understand the Finnish history in the EU ETS and the Finnish electricity markets.

Finland included 62% of all economic activities causing CO_2 under the ETS, which is high compared to other EU countries during the initial phases. This high initial coverage is largely due to Finland's industrial structure, which relies on energy-intensive sectors like pulp, metals, and energy production, as well as its cold climate, which drives higher energy demand (Kara et al., 2008). Later, especially in phase 3, the scope and coverage of the EU ETS expanded to include more sectors, and national caps were replaced with an EU-wide cap. Due to this, currently almost half of Finland's CO_2 emissions are covered by the ETS. Finland has cut down total emissions by 2% on average per year since 2005, but in the last 5 years, the reduction rate on average has increased to 5% per year (Ministry of the Environment, 2024).

Finland's emissions are decreasing significantly, especially in the energy sector. By spring 2025, all installations that used coal in energy generation were closed or replaced by alternative fuels (Ministry of the Environment, 2025). However, according to the annual climate report (2025), more action is needed, especially in land management, to reach national and EU commitments. It is interesting to examine how the complete shift from coal-fired installations will impact the amount of emission allowances needed and thus Finnish electricity prices.

Figure 2 presents the development of Finnish electricity prices by the type of consumer, starting from 2010 until the end of 2025. The types of consumers represented include households with the lowest consumption, households with the highest consumption, and enterprise/corporate businesses with the highest consumption levels. The two consumer types with higher consumption were chosen as they are more likely to be affected by emission allowances. Additionally, households with the lowest consumption were not only included for diversity but also because they are impacted the most by the fluctuations in electricity prices. Examining Figure 2, it's evident that during the first ten years, there were no significant changes in the price of electricity for any consumer type. However, there is a sharp spike in the prices in 2021-2022, which then settles down a bit in 2023. The graph seems to follow the price of emission allowances in Figure 1, which indicates that emission allowances and Finnish electricity prices are at least connected in some way.

2021 marked the beginning of the fourth phase of the EU ETS, which saw a significant increase in the price of emission allowances which can clearly be seen also in the prices by type of consumers. An important takeaway is that households with low consumption are affected the most by the high prices because their electricity prices are significantly higher than any other type of consumer in Finland. This is a result of retailers adding a profit margin to the electricity prices, and because electricity, like many other commodities, is cheaper in larger quantities due to the returns to scale.

Electricity prices for all three types of consumers have stabilized since the energy crisis of 2022. However, the graph shows a long-term trend in the rise of electricity prices, especially for households with low electricity consumption. During 2025, electricity prices for enterprises and corporate clients and high consumption households seemed to decrease slightly, while the prices increased for households with the lowest consumption. When compared with the price of emission allowances, it can be inferred that emission allowances seem to follow along with the rise in electricity prices during 2024 and 2025. Whether this indicates correlation or that both variables react to market changes similarly will be examined later in the empirical section.

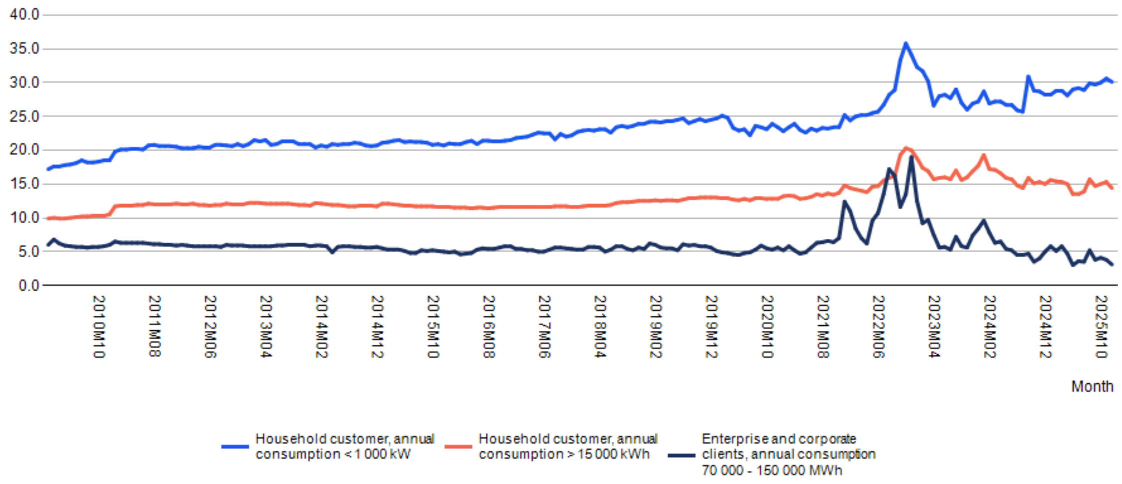

Figure 2. Price of electricity by type of consumer, Total price (c/kWh) (Statistics Finland).

In my bachelor's thesis, I used household electricity prices as the proxy for Finnish electricity prices. However, household electricity prices are not a great proxy for electricity prices because they include regulation, taxes, and other factors that are not part of the marginal cost of generation. In this thesis, however, the Finnish wholesale electricity prices were used as the dependent variable, which is a major improvement compared to the bachelor's thesis. Wholesale electricity prices, like household electricity prices, have stayed stable in the long-term, excluding the energy crisis in 2021-2022. The wholesale electricity prices have stabilized after the record heights in 2022.

Finland aligns with the EU's carbon neutrality goal for 2050 but is setting an even more ambitious target, aiming to achieve carbon neutrality by 2035 (IEA Finland, 2024). Due to this, Finland has been very proactive in implementing EU ETS policies and has often exceeded the mandated measures. This ambition has driven the proactive implementation of the EU ETS policies and Finland's national targets for reducing carbon emissions outside of the EU ETS coverage. As of 2024, the largest energy sources used in the production of electricity were nuclear (39.8%) and wind (23.7%). The next significant sources were hydropower (17.5%) and biofuels (12.3%), while only (2.8%) of electricity was generated with coal, showing Finland's transition towards low-carbon electricity (IEA Finland, 2024). Finland is part of a power exchange called the Nord pool with other Nordic countries: initially, Sweden, Norway, and Denmark, and now many more. This multinational electricity market sets electricity prices transparently based on supply and demand from electricity producers, energy suppliers, and large consumers (Nord Pool, n.d.). Nord Pool prices are updated by hourly supply and demand, causing significant fluctuation in Finnish electricity prices during peaks of high demand. Cross-border trading also means that fluctuations in prices in other countries under the Nord Pool affect Finnish prices too.

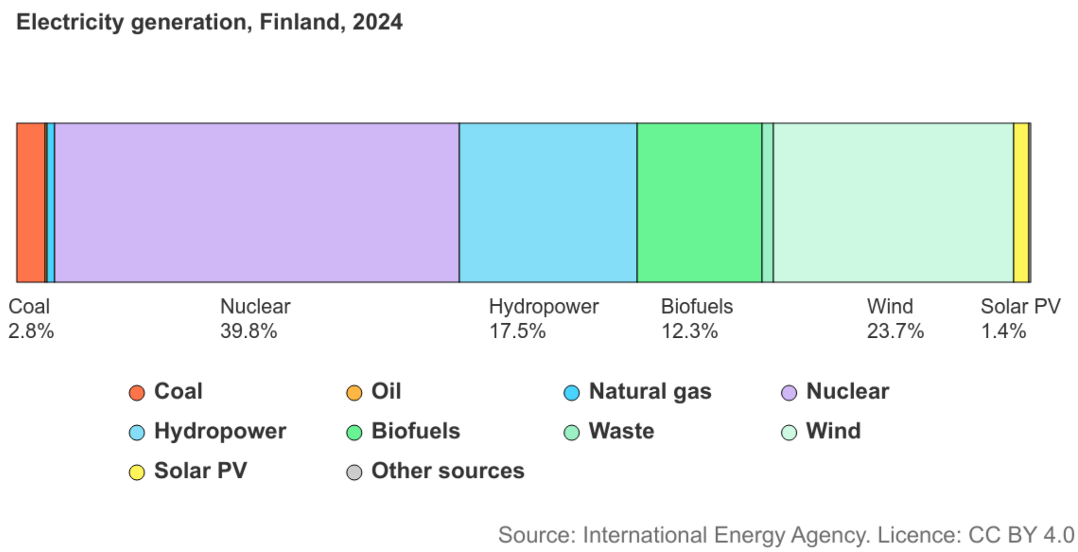

Figure 3. Electricity generation sources in Finland, 2024 (International Energy Agency)

Compared to the year 2023, there has been great progress towards carbon neutrality and interesting shifts in the sources of electricity generation. In 2023, hydropower was still the second largest source of electricity generation, but now wind is significantly larger. As illustrated in Figure 5, the use of wind energy in electricity generation has increased with constant growth. The use of coal decreased by half, and other energy sources decreased slightly too, largely because of the sudden increase in wind power. The significant increase in wind power is a positive indication that reaching carbon neutrality by 2035 is a real possibility.

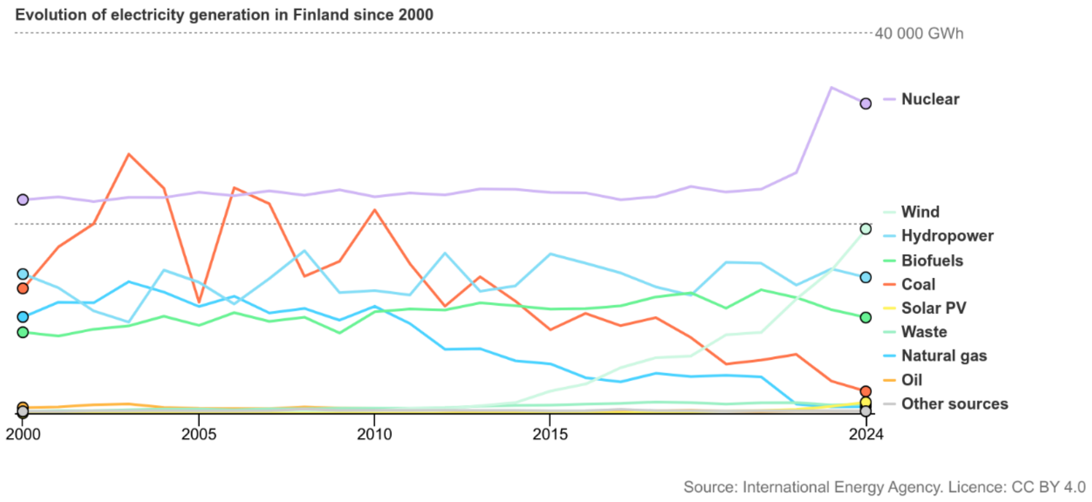

Figure 4. Evolution of electricity generation in Finland since 2000, 2024 (IEA).

Despite this positive shift, Finland's energy mix is very diverse, and compared to electricity, it uses far more carbon-intensive energy sources. The primary sources of energy in Finland are biofuels and waste, with 31.8 % and nuclear energy with 27.3 %. Approximately one-third of Finland's energy production is generated from carbon-intensive sources: oil (20.8%), coal (5.9%), and natural gas (4.4%) (IEA Finland, 2024). According to the same report, only 4% of the generated energy was from hydro and another 4% from solar. This diverse energy mix can have significant implications for electricity prices in Finland. The use of carbon-intensive energy sources can increase electricity prices in times of high demand. During periods of high demand, Finland might have to rely on carbon-intensive energy sources, increasing costs in the form of purchased carbon allowances.

Although the use of oil, natural gas, and coal has been consistently decreasing, Finland is still dependent on oil in the total energy supply. This is not part of domestic energy production but rather the oil that is exported from other countries to match the energy demand. Until the entire electricity generation is completely carbon-free, the use of carbon-intensive energy sources in the total energy supply will have an impact on the electricity sector as well.

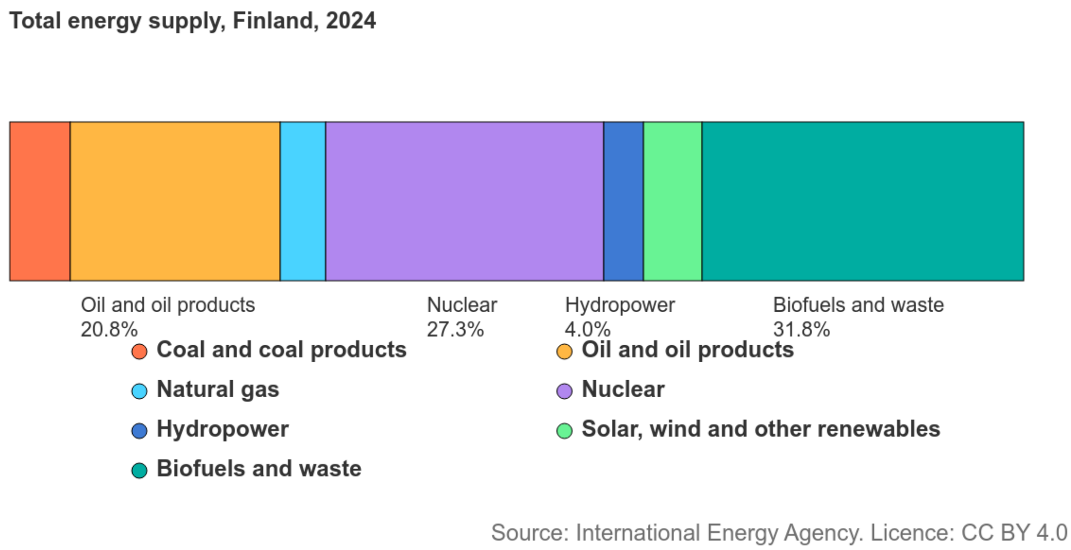

Figure 5. Total energy supply in Finland, 2024 (International Energy Agency)

2.3 Nordic electricity market

Although the electricity mix of Finland is largely carbon-free, domestic production is not the sole factor influencing electricity price formation. Electricity is a traded commodity sold based on demand and supply within an integrated market. Electricity is exchanged between countries in the European Union emission trading system, which means that generation conditions in one country affects others also. Finland is part of the Nordic electricity market, Nord Pool, which initially consisted of the Nordic countries but has since expanded to include several additional European countries. Therefore, Finnish electricity prices may be influenced by the electricity mixes of the other countries participating in the Nord Pool.

Nord Pool is the first power exchange in the world, and it is still one of the key power exchanges in Europe (Nord Pool, n.d.). The primary goal of Nord Pool is to offer cross-border electricity trade by integrating national electricity markets through a common place wholesale electricity market (Nord Pool, n.d.). By offering electricity trading across different countries, Nord Pool is promoting market integration and competitiveness which should improve price efficiency and make the sector more durable during crises and shocks. At the same time, increase in market integration implies that electricity prices become more sensitive to external factors such as energy policies, weather conditions, and supply constraints in neighbouring countries, which also transmits shocks across national markets.

Electricity is primarily traded in the day-ahead market, where participants buy and sell electricity on the following day in a closed auction (Nord Pool, n.d.). The prices are set hourly, ensuring that electricity supply equals demand in each bidding zone (Nord Pool, n.d.). In this market the marginal unit determines the price of electricity in each hour. As a result, the electricity generation structure in other Nord Pool countries can influence Finnish electricity prices. The marginal pricing mechanism will be discussed in more detail during Chapter 3.

Over time, the Nord Pool market has become more integrated, which has increased cross-market risk transmission (Uribe et al., 2020, pp. 7–8). While risk transmission implies that shocks can spread across countries, Uribe et al. (2020, p. 8) also argue that it can reduce the risk of severe domestic disruptions by allowing markets to share supply shortages, effectively diversifying risk across the region. This means that an electricity shortage in one country does not necessarily lead to a national crisis because other countries can provide support through imports. Do and others (2024, pp. 24–25) also find that interconnectedness in European electricity markets has increased significantly, particularly in Western Europe and the Nordics, and that the direction of spillovers depends on whether a country is a net transmitter or net receiver. Finland is one of the most important net receivers in European electricity markets, meaning that shocks in major exporters such as Sweden and Germany can influence Finnish electricity prices.

The Finnish electricity market does not function in isolation but is closely tied to other European electricity markets through cross-border trade. This integration has significant implications for electricity price formation in Finland, as shocks from neighbouring countries can be transmitted through the Nord Pool market. As a result, cross-border spillovers must be accounted for when analysing the relationship between emission allowances and electricity prices, particularly given Finland’s role as a net receiver within the integrated Nord Pool market. This consideration has been incorporated into the empirical analysis of this thesis.

3 Theoretical background

This chapter presents theoretical concepts related to the analysis of the relationship between emission allowances and electricity prices in Finland. First ETS will be explained more rigorously and its usefulness compared to other relevant climate policies is discussed briefly. Next, the theory of externalities and marginal abatement cost are explained both of which are critical concepts for the reader to understand. Following this electricity price formation is explained more in detail which is necessary to understand which variables are important in the empirical research. Finally, the current challenges facing the EU ETS will be briefly discussed to add nuance.

3.1 Emission trading system

Environmental policy instruments can broadly be divided into economic and non-economic instruments (Saha, 2024, p.36). Economic instruments, often referred to as market-based instruments, influence behaviour through price signals rather than direct regulatory action. The Emission Trading System is part of this category along with environmental subsidies and different types of pollution taxes (Saha, 2024, p.36). On top of being a market-based instrument, The ETS is also a quantity-based instrument, meaning that there is a limit set on total emissions which is then divided into tradable permits (Saha, 2024, p.43). Quantity certainty is one of the key reasons why policymakers have adopted ETS as the cornerstone of climate policy in the EU.

Market-based policies are generally considered more flexible than command-and-control policies because they allow emission reductions to be executed where it is most cost-effective (Guo et al., 2021, p.5). This flexibility constantly incentivizes companies to invest in innovation and to adopt less carbon-intensive technologies to minimize losses from exceeding the emission limit. In addition, when regulations do not have precise information about firms' abatement costs, market-based instruments can achieve reductions more efficiently by decentralising decision-making to market actors (Saha, 2024, p. 43). On the other hand, Command-and-control instruments offer administrative efficiency and direct enforceability, but this usually requires extensive information in order not to create long-term market inefficiencies (Saha, 2024, pp. 36-37). The ETS and other market-based instruments are often preferred as climate policies because they set a price on carbon and therefore include it as a cost in the production process.

The ETS is a carbon-pricing instrument which means that it utilizes market mechanisms to transfer the cost of carbon to polluters. There are other carbon pricing instruments of which the most notable one is the carbon tax. The primary strengths of carbon taxes are the certainty of cost and the ease of establishing and administering the instrument. However, carbon tax does not provide certainty of emission quantity which the ETS does offer with the emission cap (Green, 2021, p.2). In the EU, the ETS is preferred over carbon taxes because they force the reduction of emissions while allowing flexibility in the execution. However, usually countries or institutions utilize multiple different carbon pricing instruments simultaneously to cover a larger number of emissions. In practice, these two carbon pricing instruments both reduce emissions and work together well (Haites, 2018).

3.2 Marginal abatement cost

The theory of externalities is strongly related to carbon pricing and therefore the ETS. An externality is an unintended consequence caused by one party's action that impacts an uninvolved third party either positively or negatively (Bellinger, 2016, as cited in Perrels et al., 2006). In this case, carbon GHG emissions are the negative externality that is caused by the power sector's electricity production. GHG emissions cause climate change which in the long run causes harm to the environment, society and economy. Clean air and climate are both public goods which need to be allocated efficiently to avoid market failure. Market failure is an economic situation where resources are not efficiently allocated, and market activities cause more negative effects than positive (Dos Santos & Ribeiro, 2022). Negative externalities, such as GHG emissions, lead to market failure. Santos and Ribeiro (2022) argue that government or in this case, EU intervention is needed, because companies are responsible for GHG emissions and therefore they should be mandated to pay for the cost of the negative externality. To offset this externality carbon pricing instruments such as the ETS set a certain price for carbon making it part of firms' cost of production.

The new price of production has the negative externality internalized into it. The price of reducing or replacing externality within a company's production is called the abatement cost. Marginal abatement cost is a key theory that is linked to carbon pricing. Marginal cost is a fundamental economic theory that explains how much producing one additional unit costs (Harris & Roach, 2023, p. 46). Marginal abatement cost describes the cost of reducing one additional pollution unit and the costs of different abatement measure vary. (Harris & Roach, 2023, p. 343). Companies with lower MAC can cut down their emissions more effectively whilst companies with high MAC can buy allowances from the carbon market. MAC curves (MACC) are economic modelling tools that measures the marginal cost of emission abatement for different emission amounts (Fischedick et al., 2011, p. 832). MAC tends to increase constantly until reducing an additional pollution unit becomes too expensive imitating the traditional supply curve (Fischedick et al, 2011, p. 832). This concept supports the argument of the cost-effectiveness of the ETS. The upward curve of MACC occurs because the most inexpensive emission reduction measures are implemented first and additional reductions demand more expensive technologies and adjustments.

Figure 6 describes, on the left the marginal abatement cost of one additional unit for each different method of reducing emissions. The figure on the right presents the relationship between the marginal abatement cost and emission abatement. In the MAC curve each step resembles an abatement measure and how much it reduces emissions and how much it costs to implement. The relationship between emission abatement and cost of abatement is positive indicating that as the total amount of emission abatement increases the marginal cost of abatement increases as well. The emission abatement measures that have a negative abatement cost, such as LED lights, indicate that the most cost-effective measures lead to economic gain and net profit. Renewable energy sources such as nuclear, offshore wind, and solar are a quite cost-effective way of reducing carbon emissions. Adapting renewable energy would also mean lower electricity prices because the cost of carbon passed on to electricity prices wouldn't be as high as with non-renewable energy sources and less clean ways of producing electricity.

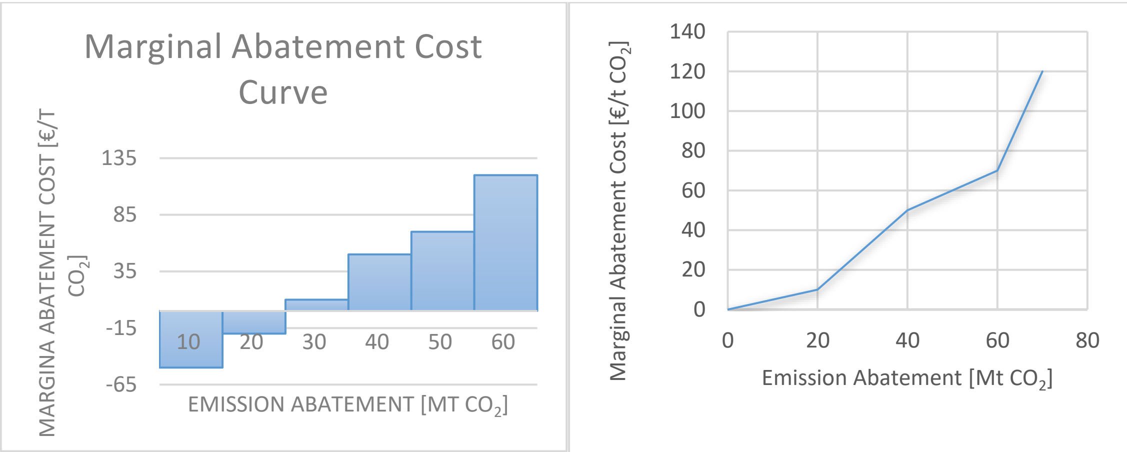

Figure 6. On the left is an illustration of a MAC curve and on the right an illustration of the relationship between emission abatement and MAC cost.

However, MAC curves have received critique from economists regarding the validity of using them as the sole policy tool in decision-making. Notably Kesicki and Etkins (2012) have criticised the over-reliance on MAC curves despite their several drawbacks related to the curves' simplicity. They state that MAC curves should be utilized in the planning phase of future climate policy by illustrating the abatement costs of different emission abatement methods. MAC curves should not be used as the final tool to evaluate abatement instruments (Kesicki & Etkins, 2012).

3.3 Electricity price formation

As this thesis is analysing how emission allowances affect electricity prices, it is crucial to understand how electricity prices are formed and what factors have an impact on it. Electricity, like most commodities, is priced based on supply and demand on the market (German & Roncoroni, 2006, p. 1225). Suppliers in electricity markets are the power companies that generate electricity, and demand consists of both electricity retailers, who also sell electricity and the final end-consumers like households and small businesses. However, compared to other commodities, electricity is unique due to high price volatility, extreme spikes in volatility, and the inelasticity of demand in the short term. The source of energy used in electricity production has a significant impact on electricity prices as well (Afanasyev et al.,2021). Part of the reason why electricity prices are so volatile is explained by the lack of storage capacity which would reduce spikes and volatility (German & Roncoroni, 2006, p. 1226). For this reason, relatively small changes in fundamental drivers cause significant spikes in the electricity prices. (Afanasyev et al,. 2021).

The fundamental factors that drive electricity prices are demand, capacity of electricity (supply), climate, and energy cost (Afanasyev et al.,2021). Climatic factors and weather conditions are very significant drivers, especially in Finland's electricity prices. Cold climates increase the cost of electricity because the demand for electricity increases due to the excess use of heating during winter. On top of that, weather conditions such as the amount of sunlight and wind affect the production of wind and solar energy directly. Wind power produces 18.1% of Finland's electricity, making this factor very significant (IEA, 2023). Afanasyev and others (2021) also mention that the significance of price drivers of electricity prices depends on the timeframe that's being looked at. In the short-term demand doesn't have a strong effect on electricity prices, but in the long term, the effect is stronger. Unlike climate and weather conditions, whose effects are stronger in the short term rather than long term (Afanasyev et al., 2021). Finally, under the EU ETS, the price of carbon influences the price formation. The significance of carbon cost depends on the amount of carbon-intensive energy sources used in electricity generation. This will be discussed and analysed thoroughly later.

Determining what drives the price of carbon in the EU ETS is a very interesting concept when studying the effect of emissions allowances on electricity prices. Aatola and others (2013) investigated the carbon prices during the first and second phases of the EU ETS. They found out that 40% of the price of carbon was explained by the market fundamentals of which the most notable ones were the prices of electricity, coal, and gas. Coal and gas are used a lot in the electricity production in Germany explaining why they had such a big impact on carbon price (Aatola et al., 2013). In Finland coal and gas impact electricity prices but they are not nearly as significant compared to Germany. Similar fundamental drivers in Finland would be the cost of wind- and hydropower for instance. An important and logical insight from the study was that EUA price is explained heavily by the cost of electricity production (Aatola et al., 2013).

A crucial theoretical aspect of the ETS is its effect on electricity prices through the cost pass-through mechanism and price elasticity. The pass-through mechanism explains how much of the emission allowance prices are transferred to electricity prices by power companies (Jouvet & Solier, 2013, p. 1370). Essentially, this examines how effectively power companies pass the cost of carbon to consumers. In theory, under perfect competition, the pass-through rate of carbon also known as the add-on rate, should be 100% (Sijm et al., 2006). However, Sijm and others (2006) note that this is not the case due to other variables such as demand elasticity. They found empirically that the pass-through effect of carbon cost is somewhere between 60%-100% in the wholesale power markets in Germany and the Netherlands.

In Figure 7, Sijm et al (2006) demonstrate the merit order by ranking each energy source by its cost from cheapest to the most expensive. It shows the add-on cost of carbon emissions on the electricity prices produced with each energy source. Also, on the right side of the figure, there is the average electricity price added on top of the CO_2 work-on rate. Add on rate is the opportunity cost of adding the cost of carbon emissions to the electricity price. On the other hand, the work on rate is the general increase in electricity price due to the carbon emissions costs. (Sijm et al., 2006). This is a fundamental concept for the later analysis of what impact emission allowances have on Finland's electricity prices.

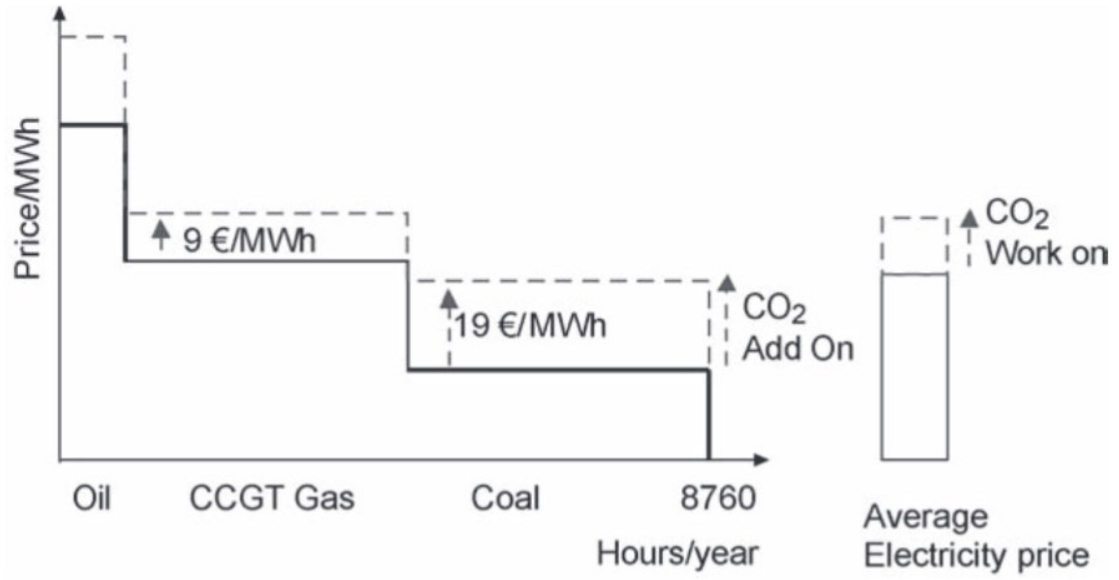

Figure 7. Pass-through of CO_2 opportunity costs for different loadperiods (at a price of d20/tCO_2) (Sijm et al., 2006).

Price elasticity of demand explains how strongly changes in price impact demand (Harris & Roach, 2021, p. 680). If a commodity has a high price elasticity of demand, changes in price can have constraints on the pass-through mechanism because the new reduced level of demand may not require the supply of electricity from more expensive generators (Sijm et al., 2006, p. 51). Electricity has a low-price elasticity because households and other small consumers are not quick to change their electricity consumption (Sijm et al., 2006). However, an increase in electricity prices can cause a change in demand in the long term. Another variable that affects the pass-through effect is the merit order which calls power plants to meet the electricity demand in the order by cost (Sijm et al., 2006). Clean energy sources which have low, or zero CO_2 costs rank higher in the merit order thus pushing the power sector in the direction of carbon neutrality.

3.4 Challenges facing the EU ETS

There are also issues that have arisen after the implementation of the EU emission trading system. Carbon leakage is one of the key issues that threatens to undermine the effectiveness of the ETS (Misch & Wingender, 2024). Misch and Wingender (2024) define carbon leakage as the increase in foreign pollution due to policies on domestic emissions. In other words, power companies transfer their production to countries with less strict regulations on carbon emissions. The EU has responded to this challenge by developing a new climate policy tool called the carbon border adjustment mechanism (CBAM). The CBAM sets all imports coming outside of the EU ETS a carbon tax equivalent to the price of carbon used in production (Lan & Tao, 2024, p.2). This is done to protect the competitiveness of European industries operating under the ETS and prevent carbon leakage. However, there is a danger that CBAM might cause friction in international trade and worsen international relations. CBAM can be seen as an international trade barrier that violates international trade agreements and principles (Lan & Tao, 2024, p.4). Lan and Tao mention that these practices would especially affect developing countries negatively, which could be seen as discriminatory and protectionist. The CBAM is a new climate policy tool that will be fully implemented and functioning in 2026, so the real effects of this policy remain yet to be seen.

One of the major critiques that has faced the Emission Trading System has been the high price volatility and price uncertainty of emission allowances. This can be problematic because it can influence electricity prices, which in turn impact households. Morao (2025, p. 8) found that strengthening carbon policy led to measurable increases in consumer prices across multiple commodities, especially energy. The impact remained visible for approximately two years after the initial policy implementation (Morao, 2025, p. 8). Emission allowances are still only one factor that impacts electricity prices, along with other variables discussed in this chapter, all of which are important when analysing the price formation of Finnish electricity prices.

3.5 Empirical review of extant literature

Next, in this thesis, there will be a review of previous studies that analyse the effects of carbon emissions allowances on electricity prices in different EU countries. The purpose of this review is to figure out how previous methods and findings could be applied to the case of Finland and this thesis. The EU countries examined will be similar to Finland and any significant differences between the countries will be discussed and considered in this review. The emphasis will be on the methods and variables used in the studies, and on seeing if they can be utilized in the empirical analysis of this thesis. The three most common approaches used in analysing emission allowances and electricity prices in the existing literature are the price drivers' approach, the error-correction model, and the pass-through of carbon cost.

Sijm and others (2006) found that the cost pass-through of carbon in Germany and the Netherlands was between 60%-100%. Their study was one of the first ones analysing the relationship between emission allowances and electricity prices, and it focused on the pilot phase of the EU ETS, meaning that most of the emission allowances that passed through to electricity prices were allocated freely. The main implication of this study was that, even though during the first phase of the EU ETS emission allowances were allocated mostly freely for power companies, they still transferred most of them to electricity prices rather than absorbing the cost of carbon. Sijm and others (2006) explain that the reason for this is that emission allowances cause an opportunity cost for the power companies, independent of the allocation method for these allowances. This finding would imply that in later phases of the EU ETS, the effect of the pass-through of CO_2 to electricity prices would intensify as more emission allowances would be allocated through auctions.

These findings were further supported by Perrels and others (2006), who came to similar conclusions. Perrels and others (2006) investigated the same phenomena using an error correction model, and they investigated Finland's wholesale electricity markets, therefore making this academic paper very useful and relevant for this thesis. The error correction model is a useful method in this case because it captures both short-term and long-term changes in electricity prices caused by carbon costs. They found that 75%-95% of the price of emission allowances was transferred to Finland's electricity prices. This study confirms that emission allowances indeed had a significant impact on Finnish electricity prices at least during the pilot phase of the EU ETS.

Fabra and Reguant's (2014) paper is a benchmark empirical study for analysing the ETS cost pass-through in electricity markets, on which many of the later academic papers related to this topic rely. It further proved that emission allowances are almost completely passed through to electricity prices even if they are freely allocated. However, the key contribution of this paper is the analysis of why pass-through rates specifically in the electricity markets are so high, which Fabra and Reguant attributed to supply, demand and markup adjustments. Because of the richness of their micro-level data, they were able to conclude that high cost pass-through is explained by weak incentives for markup adjustments and the lack of price rigidities. Although, this thesis will not be using micro-level data, it is useful to understand the results in the empirical section.

Kirat & Ahamada (2011) in their study compare two EU countries Germany and France to find out whether the EU ETS is an effective CO_2 reduction tool determined by the pass-through rate of carbon to electricity prices. Their analysis's timeframe covered the pilot phase of the EU ETS from 2005-2007. They chose France and Germany because these countries have very different energy-mixes, which is an important point of examination in the study. The emphasis on the impact of energy-mix is useful for this thesis because Finland's energy-mix is unique, and it logically should have a significant effect on electricity prices. Most of France's electricity is currently produced with nuclear energy and other low-carbon energy sources whilst Germany still relies heavily on carbon-intensive energy sources such as coal and natural gas (IEA France, 2023) (IEA Germany, 2023). Due to this study being published in 2011, the energy mixes of both countries are not as low carbon as they are currently, but this analysis and econometric model are still useful for the thesis's purposes.

Kirat & Ahamada (2011) built a time-series model where electricity price is dependent on climate variables, temperature, rainfall, brightness, and the type of energy used in production of electricity. They used day-ahead and month-ahead electricity prices and carbon spot prices. Kirat and Ahamada's (2011) first key insight are that the impact of carbon pricing was strongly dependent on each country’s energy mix, affecting Germany’s electricity prices more than France's. This could be relevant for Finland’s electricity prices since its energy mix has a low-carbon intensity like that of France. The second insight was the stronger correlation between wholesale electricity markets of the countries due to the EU ETS implementation (Kirat & Ahamada, 2011). Finland being part of Nord Pool might indicate similar correlations between the Nordic wholesale electricity market participants.

The pass-through rate of carbon to electricity prices explains how completely emission allowance prices transfer to electricity prices (Jouvet & Solier, 2013). Jouvet and Solier conducted a study of 10 EU countries’ pass-through of CO_2 onto electricity spot prices in the first phase and in the first 3 years of the second phase of EU ETS. This study is important because Jouvet and Solier were the first ones to examine whether carbon prices would transfer to electricity prices outside the pilot phase. Also, the 10 EU countries at the time covered 80% of the fossil fuel-generated electricity in Europe (Jouvet & Solier, 2013). Nord Pool was included as one of the countries which means that the study is directly relevant to Finland too. Jouvet and Solier found out that there seems to be no pass-through of CO_2 costs to electricity prices during the first three years of phase 2. They assumed that this result was due to economic shocks in Europe mainly the financial crisis in 2007. Energy prices have a great effect on electricity prices, so when their price fell due to the crisis, electricity prices fell with them (Jouvet & Solier, 2013). This study demonstrates well that external factors like sudden economic crises can have a significant effect on electricity prices. There are many drivers of electricity prices which makes them vulnerable to different changes in the economy.

Hintermann (2016) in his paper analyses the pass-through rate of carbon costs to hourly electricity prices in Germany. This study allows a more precise examination of changes in electricity prices and market dynamics. It also gives us the opportunity to better examine the impact of renewables, temperature, and time of day on electricity which are relevant factors for a country like Finland. Hintermann (2016) found that the pass-through rate of CO_2 costs in Germany was complete and thus there is no need for free allocation of emission allowances. Free allocation of emission allowance is done to protect European industries from carbon leakage, but these results showed they were not used as intended by the German power companies (Hintermann, 2016). Finland uses a lot less carbon-intensive energy sources than Germany which leads to a reduced need for emission allowances and therefore lower electricity prices. However, due to differences in energy-mixes the pass-through rate of carbon allowances might not be the same.

Dagoumas & Polemis (2020) conducted an econometric analysis on the carbon pass-through in Greek from 2014 to 2017 and found an almost complete pass-through of carbon costs to electricity prices. They used a rich micro panel with hourly intra-day data which was consistent with Hintermann's (2016) and Fabra and Reguant's (2014) findings. Their result implies that using aggregate data can still capture the impact of EUA in the electricity markets.

Analysing the Nordic region gives us good comparisons for our study of Finland's electricity markets because they are all small open economies with similar energy-mixes and governmental policies on climate. On top of that, they are all part of Nord Pool, a multinational power exchange, which makes all the participants' national electricity markets more connected and correlated. Vaissalo and others (2024) did empirical research on the volatility relationship between Nordic electricity markets and carbon emission allowances using a dynamic conditional correlation model. The key insight derived from this study was that volatility and returns flow from Nordic electricity markets to the European Union Allowance (EUA) market but not the other way around (Vaissalo et al.,2024). Due to the mean correlation between the variables being positive, an increase in emission allowances suggests a small increase in Nordic electricity prices. This means that other variables such as Nordic energy-mix and climate can have a greater impact on Nordic and therefore on Finland's electricity price formation. This implication is very significant because it would support the previous observations of this thesis about emission allowances not having a strong impact on Finland's electricity prices as in other EU countries.

Vaissalo and others (2024) used Nordic electricity prices and EUA prices from EEX in the model. This makes it easier and clearer to analyse the relationship between these two price sets, especially during long time periods. This study covers the period from 2009 to 2023. With the previously mentioned cost pass-through analysis it is more complex to cover long time periods because usually cost pass-through models contain more variables that need to be considered. The dynamic conditional correlation model explains the correlation between electricity prices and emission allowances but unlike the cost pass-through rate, it doesn't explain what the quantifiable effect of emission allowances on electricity prices are. However, it is still a useful model, and it makes it a lot easier to understand the movements and relationships between these variables because it highlights patterns that could be otherwise difficult to detect.

More recent academic literature on the topic has, however, shown that there might be a negative relationship between emission allowances and electricity prices. Wolff and Feurriegel (2019) found this to be the case empirically in the short run during the third phase of EU ETS in the EPEX day-ahead and intraday markets. The implication is that if the price of emission allowances increases the price of electricity prices decrease. One possible reason could be that the price of emission allowances has been too low to have a significant effect on the formation of electricity prices. Another reason can be that power companies have switched their energy sources to less carbon-intensive so there is not as much need for emission allowances. (Wolff & Feurriegel, 2019). This might be a significant reason why emission allowances might not affect Finland's electricity prices as much as theory would imply. The last potential reason could be that due to a merit order mandating the premier use of renewably sourced electricity before electricity generated by carbon-intensive methods, emission allowances have a weaker effect on electricity prices when demand for it is low (Wolff & Feurriegel, 2019).

Wolff & Feurriegel (2019) used an autoregressive time series model for each hour of the day, which allows them to analyse price dynamics and variations in electricity production. They also did quantile regression to address nonlinear pass-through which has been noticed in prior research. The independent variable was the price of EUA, and the dependent variables were wind- and solar infeed, grid load, and dummy variables for both weekdays and months. The main limitation for this study is that it focused on the short-term relationship between emission allowances and electricity prices (Wolff & Feurriegel, 2019). In the long run effects of carbon pricing might affect electricity prices differently which calls for more research. Another limitation is the exclusion of non-renewable energy infeed from the models, which can ignore significant effects on electricity prices because carbon-intensive energy sources react strongly to emission allowances. Although merit order prioritizes renewable energy sources in electricity production, the price of electricity is set by the cost of production of the last unit of electricity produced.

Bai and Okullo's (2023) research support the consensus reached by the previous literature but is significant because the timeframe from 2008 to 2018 extends to the third phase. Bai and Okullo (2023) found that allowances were almost completely transferred to electricity prices for seven European countries. Therefore, the high-cost pass-through rates of European electricity markets have not significantly changed despite of changes to the ETS and the increase of renewable energy use. The paper also supports the findings of Fabra and Reguant (2014) and allows analysis without observing marginal generation technologies directly because they are reflected in the EUA and electricity prices as shown by Bai and Okullo (2023).

The research done on the EU ETS and the relationship between emission allowances and electricity prices is abundant. Especially the first and second phases of the EU ETS have been covered extensively. However, there has been less attention on the third phase and especially the ongoing fourth phase. This is a significant gap in the literature because the emission trading system has undergone recently a lot of changes, and their effects ought to be researched more thoroughly. In a similar manner, countries like Germany and France have been covered rigorously but the Nordic region and Finland has a lot less academic literature especially for the third and fourth phases of the EU ETS.

4 Data and Methodology

In this chapter, the data and methodology used in the empirical analysis are discussed. First, the variables chosen for the empirical analysis were introduced and the process of extracting the data variables. In the methodology section, the empirical methods used in the analysis were discussed as well as the justification why the methods were chosen. Finally, any limitations concerning data or methods are discussed before continuing to the results.

4.1 Data

All the data is in daily frequency, and the data period is from the 1st of January 2021 until 30th of September 2025 covering the current fourth phase of the EU ETS. I purposefully excluded the previous phases to properly analyse the impact of carbon cost on electricity prices when EUA prices are sufficiently high. In addition, 2021-2025 is an interesting period for electricity markets because of the energy crisis of 2022. The variables used in the empirical study were Finnish wholesale day-ahead electricity prices, EUA futures prices, interest rates, fuel prices, nuclear-, hydro- and wind power production, wind speed, temperature, electricity load and cross-border flows from Sweden, Estonia, and Norway. Further details about the variables and data sources can be found in Table 1.

Daily price frequency was chosen to capture how independent variables impacted Finnish day-ahead prices during the fourth phase of the ETS. Daily data is more econometrically detailed than monthly data and allowed the addition of more variables without causing issues with the degrees of freedom. In addition, it decreased the risk of multicollinearity regarding fuel prices and EUA prices since the price differences are harder to notice using monthly data.

The energy sources used in electricity production were included to capture Finland's energy-mix and to see how they impacted Finnish wholesale day-ahead electricity market. Fuel prices, oil, gas and coal were added because the marginal generator sets the price of electricity under the EU ETS (Fabra & Reguant, 2014). However, due to strong multicollinearity between oil, coal and natural gas prices, oil was excluded from the final regressions, as it represents only a small share of total Finnish electricity generation. Nevertheless, despite of Finland's relatively small use of carbon-intensive energy, they can still have a significant impact on electricity prices. Weather variables were added also because they play a significant role in the availability of renewable electricity generation namely wind and solar. Solar power production was excluded from the model because it's share in electricity generation is relatively small, and temperature already incorporates solar power as a proxy. Electricity load was included to capture Finland's electricity demand. Finally, cross-border flows were included because within an integrated European electricity market other countries' electricity markets and environmental policies have an impact on Finland's electricity market, as discussed at the end of chapter 2.

Variable	Description	Unit	Source
EUA_price	EU emission allowance price (EUA), futures	€/tCO_2	Bloomberg
Electricity_price	Day-ahead electricity price (Finland)	€/MWh	ENTSO-E
Load	Average electricity load (Finland)	MW	ENTSO-E
Interest rates	Euribor rates, 3-month, daily values	%	Bank of Finland
Wind speed	Average wind speed	m/s	FMI
Temperature	Average temperature	°C	FMI
Oil	Brent crude oil spot price	€/barrel	EIA
Gas	Dutch TTF natural gas price	€/MWh	Bloomberg
Coal	API2 coal price (CIF ARA)	€/tonne	Bloomberg
CB_EE	Cross-border electricity flow (Estonia)	MW	Fingrid
CB_SE3	Cross-border electricity flow (Central Sweden)	MW	Fingrid

CB_NO	Cross-border electricity flow (Norway)	MW	Fingrid
Nuclear	Nuclear power production	MW	Fingrid
Hydro	Hydro power production	MW	Fingrid
Wind	Wind power production	MW	Fingrid

Table 1. Details of variables used in empirical analysis.

Finnish electricity day-ahead prices were taken from the ENTSO-E transparency platform and electricity load from ENTSO-E power statistics, and both were aggregated to daily data from hourly data using pivot tables in Excel. Energy-mix variables wind, nuclear and hydro were chosen because they are the most significant energy sources used in electricity production in Finland. Wind power, nuclear power and hydro power generation data was extracted from the Fingrid's data portal and aggregated from 3-minute real-time data to daily data using Excel's pivot tables. EUA prices were extracted from Bloomberg as daily prices from the ICE Endex. Three-month Euribor rates were used as the representation of interest rates, as they represent at which rate banks in the EU lend money to each other and thus reflects the economic environment of the eurozone. Interest rates can impact electricity prices through inflation and increased production costs, so it is a good addition to the empirical model. Euribor 3-month interest rates were extracted from the Bank of Finland's database as daily values.

Brent crude oil data was extracted from the U.S Energy Information Agency (EIA) as daily prices. The unit was converted from USD/barrel to EUR/barrel using an exchange rate series from 2021 to 2025 taken from Federal Reserve Bank of St. Lois (FRED). Brent crude oil was chosen to be a proxy for oil price because it is the most significant price benchmark in Europe. API2 coal price was also converted from USD/tonne to EUR/tonne using the same exchange rate series as with oil. API2 coal price and Dutch TTF natural gas price was both extracted from Bloomberg as daily data. API2 coal and Dutch TTF natural gas were chosen as the proxies for coal and gas prices as they are both used as benchmarks in pricing in Europe. In this thesis fuel prices are used instead of fuel power generation because fossil fuel power plants can often set the marginal price of electricity even though the share of fossil fuels in power generation is small. This will cultivate better and more accurate results.

Daily mean temperature and wind speed data were extracted from Finnish Meteorological Institute (FMI). The daily averages were taken from three different weather stations which where Helsinki-Vantaa airport, Oulu airport and Tampere-Pirkkala airport. The weather stations were chosen based on geographical location to capture climate differences but more importantly to capture most of the electricity demand in Finland based on population and infrastructure. Wind speed data was converted from hourly to daily data from the same three stations.

Cross-border flows with Sweden, Norway and Estonia were extracted from the Fingrid database. The datasets of Sweden (SE3) and Estonia (EE) describe commercial transmission of electricity in and out of Finland. Central Sweden (SE3) was chosen as the bidding zone to describe cross-border flows between Finland and Sweden. SE3 was chosen because electricity trade between Finland and Sweden occurs mainly through SE3. In addition, Central Sweden and coastal Finland are connected via Fenno-Skan cables 1 and 2, which both have the capacity to transmit 400 MW (Fingrid). Cross-border data for Norway was extracted from a dataset describing the transmission of electricity, as there was no up-to-date dataset about the commercial transmission of electricity. The measure unit for all countries was MW, and a positive sign indicated electricity transmission out of Finland and a negative sign indicated transmission into Finland. Cross-border flows include all of Finland’s neighbouring countries excluding Russia. Russia was left out of the analysis due to the lack of consistent data since 2022. Cross-border flow datasets of both Estonia and Sweden were aggregated with pivot tables from 15-minute data to daily data while Norway’s dataset was aggregated from 3-minute data.

Below, I have included Table 2, which summarizes the descriptive statistics of the variables used in the multiple linear regressions. The table shows mean, standard deviation, minimum, and maximum values as well as the median. EUA futures prices have almost equal mean and median, and the standard deviation is significantly smaller. The data distribution of EUA prices is likely symmetrical, with a tall peak meaning that the data is tightly clustered around the mean. Finnish electricity day-ahead prices have similar means and standard deviation, but the median is clearly smaller than the mean. Therefore, Finnish electricity prices are likely skewed to the right with a long-left tail, although due to mean and standard deviation being almost equal there are strong variation in the distribution. EUA prices have remained relatively stable during this period, while electricity prices have been highly volatile, which is normal for electricity markets. The gathered data was in level form because several variables such as cross-border flows, temperature, and even electricity prices have negative values in the dataset, which is not allowed in logarithmic form. Therefore, the interpretation of results is not as straightforward as with logarithmic values and requires careful evaluation.

Variable	Mean	Standard deviation	Min	Max	Median
EUA_price	71.13	13.73	31.54	97.67	71.45
Electricity_price	75.33	79.77	-203.40	890.54	56.69
Load	9288.16	1487.59	6036.71	14452.29	9017.51
Interest rates	1.78	1.77	-0.605	4.00	2.135
Wind_speed	3.67	1.27	1.10	8.95	3.53
Temperature	5.66	9.67	-24.33	24.70	5.32
Oil	74.67	15.13	41.10	123.07	72.65
Gas	59.85	47.47	15.53	339.20	40.16
Coal	140.89	81.91	52.36	400.58	109.50
CB_EE	648.67	328.31	-586.28	1034.44	744.35
CB_SE	-498.14	490.29	-1200.00	1159.63	-543.14
CB_NO	-34.09	28.22	-104.44	61.51	-37.86
Nuclear	3188.85	738.85	1471.84	4400.44	2801.16
Hydro	1525.68	378.02	575.47	2370.98	1559.78
Wind	1614.49	1224.41	68.16	5977.71	1301.94

Table 2. Descriptive statistics of variables. Excel.

4.2 Methodology

The fundamental empirical approach of this thesis is multiple linear regression analysis, where Finnish day-ahead electricity prices were the dependent variable, and EUA prices were the main independent variable. Multiple linear regression analysis is useful in explaining the dependent variable while controlling for other variables (Wooldridge, 2009, p. 68). In addition, multiple regressions have been used in most of the previous literature covering the relationship between emission allowances and electricity prices, especially in studies estimating the transmission of emission allowances to electricity prices.

4.2.1 Empirical approach

To properly analyse the impact of emission allowances on electricity prices, other factors influencing electricity price formation need to be accounted for, as discussed in chapter 3.3. Below is a theoretical formula explaining electricity price formation. The formula consists of European Union Allowance (EUA), interest rates, and fuel costs, consisting of API2 coal price, TTF natural gas price, and Brent crude oil price. Fuel costs often move in accordance with EUA prices, so it is paramount to add them to the model to account for fuel switching. Demand is captured with electricity load, and supply with hydro power, wind power, and nuclear power production, in addition to weather variables and cross-border flows.

$$EP_t = \beta_0 + \beta_1 EUA_t + \beta_2 Interest + \beta_2 FuelCost_t + \beta_3 Demand_t + \beta_4 Supply_t + \varepsilon_1 (1)$$

There were several different regressions with different variables used to analyse how the electricity price and other explanatory variables were affected. This simultaneously allowed for sensitivity testing. Multicollinearity occurs when explanatory variables are too correlated with each other, which can thereby alter empirical results (Wooldridge, 2009, p. 842). This is also a concern in this thesis since a few of the variables are correlated with each other, mainly EUA price and TTF gas price, load and temperature, and imports and supply. The risk of multicollinearity will be considered in empirical testing and interpretation of the results.

4.2.2 Cost pass-through of EUA

In the baseline regression, the only independent variable was EUA prices. The purpose of the baseline regression was to establish a clear understanding of the relationship between EUA prices and electricity prices before including other factors. The equation below is a linear regression formula, where Y_i is the dependent variable, Finnish day-ahead electricity prices, β_0 is the intercept, $\beta_1 X_1$ is the change in electricity price when X_1, EUA price changes by one unit, and ε_1 is the error term. This same formula structure was expanded into a multiple linear regression formula where X_i describes all independent variables. In the second regression, the remaining variables were added to see how it impacted the statistical significance of EUA prices.

$$Y_i = \beta_0 + \beta_1 X_1 + \varepsilon_1 \tag{2}$$

Along with the variables mentioned thus far, there are additional time-related variables that impact both day-ahead electricity prices and the control variables. Using daily data causes fluctuations in the prices throughout the week, which were controlled by adding a weekday dummy variable. Monday through Saturday were included, and Sunday was left as a base group to avoid the dummy variable trap (Wooldridge, 2009, p. 226-227). Finally, a year dummy was added to control for the energy crisis in 2022 caused by the Russian invasion of Ukraine. Simultaneously, the year dummy controls for the energy policy changes that the European Union applied during the energy crisis.

4.3 Methodological Limitations

There were three limitations related to data extraction. First, a better data source for EUA prices would have been the European Energy Exchange (EEX), but unfortunately the required data was behind a paywall, so Bloomberg was chosen as the second-best option. Second, NO4 cross-border flow data was extracted as transmission of electricity between Finland and Norway, rather than the commercial transmission of electricity. This was done because the commercial electricity transmission dataset did not have data prior to the 28th of October 2024. Third, many of the datasets were not originally in daily frequency, requiring aggregation. Furthermore, the frequency of the datasets varied quite a bit from 3 minutes to hourly data. Aggregation might have led to some loss of nuance and small changes in the regression coefficients.

As mentioned before in this chapter, multicollinearity remains a risk factor in the empirical analysis. Daily data should already limit the risk, but to test for the level of multicollinearity in variables, variance inflation factors (VIF) were used after the regressions. VIF is a useful tool to examine multicollinearity within variables, but it does not answer the question of how much multicollinearity is too much (Wooldridge, 2009, p. 99).

$$VIF_j = \frac{1}{1 - R_j^2} \tag{3}$$

An additional economic variable GDP per capita and policy variable energy taxes were at first considered to be a part of the empirical research but were excluded due to multiple factors. Energy taxes were excluded because their available data was limited and in wrong frequency. Other energy policies could have been incorporated into the research as a dummy variable, but it would cause unnecessary multicollinearity with the year dummy variable which already captures the energy policy changes done in 2022. GDP per capita was excluded as it does not add anything meaningful to the results and in this relatively short sample period there is not a significant change in the level of GDP per capita.

5 Empirical results

In this chapter, the results from empirical tests and multiple regressions are presented. First, there are graphs showcasing trends and correlations between some of the most important variables. This should give some insight into the price dynamics between electricity prices and control variables. Next are the results from multiple linear regressions, which is the main econometric method of this study. The regressions should answer the hypothesis of this study and state the level of cost pass-through of emission allowances during the fourth phase of the ETS. Finally, there are robustness and VIF checks to see if the results of the regressions are valid.

5.1 Figures and correlations

Below in Figure 8 are time series plots of Finnish day-ahead electricity prices, EUA futures, API2 coal prices, TTF natural gas prices, Brent crude oil prices, and Finland's electricity load. The Finnish day-ahead electricity price plot shows strong volatility, and the prices seem to spike around January and generally during the winter months. This is in line with the expectations that electricity prices should be higher during the wintertime. In the electricity load time series plot the seasonal spikes in demand during winter months are even more clear, and the highest demand peaks for electricity are in January. There are two outliers in the electricity price plot, -203.40€/MWh and 890.54 €/MWh, which are also the dataset's minimum and maximum values. The -203.40 €/MWh value occurred on 24th of November 2023 and was caused by an electricity trading error. The 890.54 €/MWh value occurred on the fifth of January 2024, caused by exceptionally cold temperatures, which in turn led to high electricity demand. This can be seen in the electricity load plot as well, and the maximum value of the dataset was on the fourth of January 2024.

EUA futures prices seem to move in broad accordance with Finnish day-ahead electricity prices. The two strong outliers in Finnish electricity markets probably distort the relationship between the variables by flattening the electricity price series. However, the clear spike in prices during the energy crisis in 2022, the drop in 2023, and stabilization for the rest of the series are visible in both time series.

All prices were significantly impacted in 2022, but compared to the fuel prices, EUA prices and electricity prices did not respond as drastically. The fuel prices seem to move in accordance with each other, especially the API2 coal and the TTF natural gas. Correlations between variables are needed to further analyse the relationship between the fuel prices. An important takeaway from these time series plots is that the energy crisis of 2022 plays a significant role in this empirical study and needs to be taken into consideration.

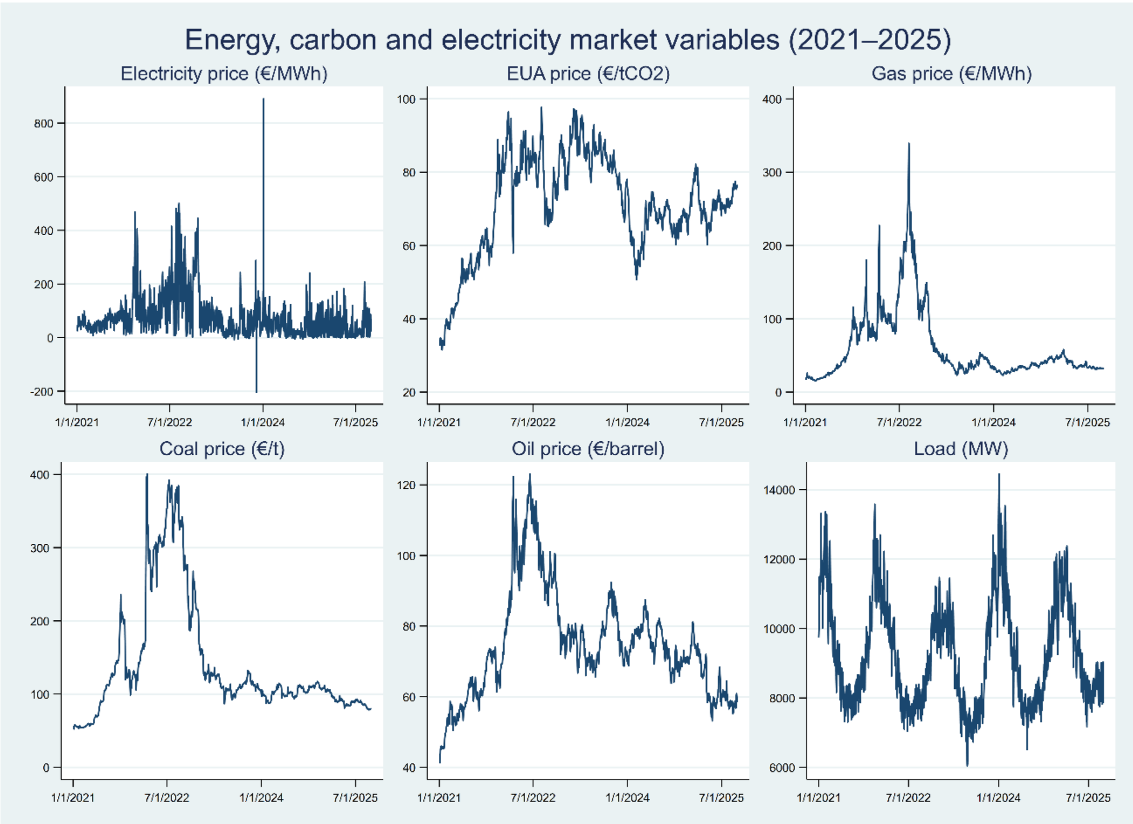

Figure 8. Timeseries plots of electricity load, EUA-, electricity-, coal-, oil- and gas prices. Stata.

The scatterplot below indicates that there is a weak positive relationship between Finnish day-ahead electricity prices and EUA futures prices. A log-log scatter plot was conducted as well to smooth out the variation caused by the two outliers in the electricity price dataset. The results in the log-log model remained pretty much the same. As EUA prices increase, the variation in electricity prices also increases. The log-log scatter plot after smoothing out the outliers shows that there is even more variation in electricity prices when EUA prices are higher. Based on these graphs, emission allowances influence Finnish day-ahead electricity prices in the short-term to some extent but there are clearly other factors at play, and the electricity prices are very volatile.

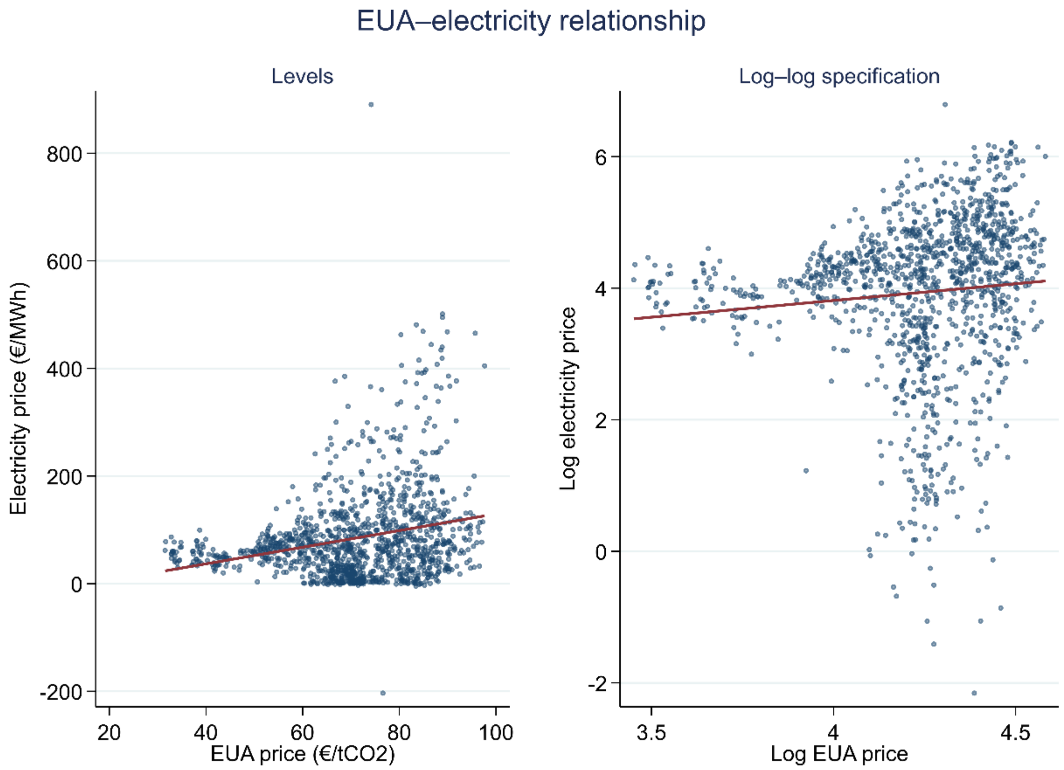

Figure 9. Level-level scatterplot and log-log scatterplot of EUA prices and Electricity prices. Stata.

A log-log correlation matrix was conducted in Stata with the same variables used in the timeseries plots to gain an initial understanding of the linear relationships between these variables. A log-log model was used because of volatility and outliers that often occur in energy -and electricity prices which can distort the results of the correlation matrixes. Although the correlation matrix is presented in log-log form to mitigate the influence of volatility and outliers, the final multiple linear regression model is estimated in levels. For consistency, a level-level correlation matrix is therefore included in the appendix of this thesis.

Based on the correlation matrix, EUA prices are weakly correlated with Finnish day-ahead electricity prices. This result is surprising since most of the previous literature on this topic has found that EUA prices impact electricity prices quite strongly in Europe. However, this result could be explained by the energy crisis of 2022 which caused the fuel prices to increase strongly leading fuel prices especially coal and natural gas to have a strong positive correlation with electricity prices. The fuel prices are highly positively correlated with each other which increases the risk of multicollinearity, which can distort the results of the regressions. Electricity load has a moderately positive relationship with electricity prices which is in accordance with the law of demand. The correlation between electricity load and other variables is negative which may indicate that Finnish electricity load is impacted heavily by seasonal factors like temperature whilst fuel prices and EUA prices vary based on macro factors especially during 2022.

	Electricity (€/MWh)	EUA (€/tCO2)	Coal (€/t)	Oil (€/bbl)	Gas (€/MWh)	Load (MW)
Electrcity	1.00					
EUA	0.09	1.00				
Coal	0.41	0.53	1.00			
Oil	0.25	0.62	0.84	1.00		
Gas	0.43	0.52	0.92	0.70	1.00	
Load	0.16	-0.23	-0.21	-0.20	-0.05	1.00

Table 3. Log-log correlation matrix. Stata.

5.2 Regression Analyses and Results

Next, a multiple regression model is applied to investigate the magnitude of the impact emission allowances have on Finland's electricity prices while controlling for other factors impacting the electricity price formation. Cross-border flows and daily temperatures are not transformed to logarithmic values because they have a lot of negative values in the datasets, which the log function cannot compute. Fuel prices and EUA prices were forward-filled to match the daily electricity prices, which is a common practice in finance academic papers.

The initial regression was conducted using a log-level ordinary least squares (OLS) model. It was divided into four different regressions to analyse how the significance of EUA prices would change when new control variables were introduced in each regression. First was a baseline regression where EUA was the only independent variable. In the second regression, fuel variables, energy-mix variables, and electricity load were added. In the third cross-border flows and weather variables were included, and in the final fourth regression date dummy variables weekday and year were added. EUA prices had a positive coefficient in all regressions, and it was statistically significant in the first, second and fourth models. R-squared was highest in the fourth regression as 0.615, so the variables explained 61,5 % of the variation of Finnish electricity prices. The whole OLS regression table is included the appendix of this thesis.

However, in the main regression in Table 4, level-level values were used as some of the variables have negative values in the datasets. To address volatility and outliers, especially in the electricity prices and energy prices, Huber/White/sandwich estimator was used to produce robust standard errors. These regressions followed the exact same steps as the OLS model, except lagged electricity prices were included in the fourth regression to address the tendency of dependent variables to be impacted by their past values. Electricity prices, especially tend to be persistently dependent on their past values.

	(1) electricity	(2) electricity	(3) electricity	**(4)** electricity
Lagged electricity				0.434*** (0.060)
EUA prices	1.330*** (0.121)	0.353*** (0.108)	0.436*** (0.108)	0.549*** (0.172)
Interest rates		12.601*** (1.201)	10.754*** (1.375)	11.248*** (2.660)
Electricity load		0.019*** (0.002)	0.026*** (0.003)	0.005* (0.003)
Natural gas prices		1.115*** (0.109)	1.064*** (0.105)	0.574*** (0.121)
Coal prices		-0.027 (0.052)	-0.008 (0.050)	-0.006 (0.049)
Nuclear generation		-0.026*** (0.002)	-0.028*** (0.003)	-0.011*** (0.004)
Hydro generation		0.006 (0.004)	0.008* (0.004)	0.007** (0.003)
Wind generation		-0.028*** (0.001)	-0.026*** (0.002)	-0.016*** (0.002)
Cross-border EE			-0.022*** (0.007)	-0.022*** (0.007)
Cross-border SE3			0.015*** (0.004)	0.008** (0.003)
Cross-border NO			-0.260*** (0.044)	-0.193*** (0.037)
Temperature			1.230*** (0.325)	-0.638 (0.390)
Windspeed			-4.383*** (1.462)	-1.984 (1.488)
Weekday FE	No	No	No	Yes

Year FE	No	No	No	Yes
R-squared	0.052	0.621	0.643	0.748
Observations	1731.000	1731.000	1731.000	1731.000

Table 4. Level-level multiple linear regression results. Models 1–4 all use robust standard errors. Standard errors are reported in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

The first model presented in Table 4 was a baseline regression where the impact of EUA prices on Finnish day-ahead electricity prices was analysed without controlling for any other variables. The result was statistically significant, and EUA prices had a positive coefficient of 1.330. The coefficient implies that a one euro increase in EUA prices leads to a 1.33 €/MWh increase in electricity prices. This result would indicate that there is a strong relationship between emission allowances and electricity prices, although this result likely has omitted variable bias, as control variables have not been introduced yet. The positive relationship follows economic theory, as an increase in emission allowance prices increases the cost of carbon-intensive electricity generation, therefore increasing the wholesale electricity price. EUA prices remained highly statistically significant, with p-values below 0.01 in all four regressions. When other control variables were added to the regressions, the coefficient of EUA decreased, but it remained positive in all, indicating that EUA prices absorbed some variation that is better explained by other variables. In the final regression, the coefficient was 0.549, which seems more realistic and in line with prior academic consensus.

In the second model presented in Table 4, natural gas prices, interest rates, electricity load, and most energy-mix variables were statistically significant and behaved mostly as expected. Natural gas prices and electricity load had positive coefficients, while wind generation and nuclear generation had negative coefficients. Coal prices were not statistically significant after interest rates were included and oil prices were excluded due to high multicollinearity. This likely reflects strong multicollinearity among fuel variables, particularly between coal and natural gas prices during the 2021–2025 energy crisis period. Natural gas appears to be the more relevant marginal fuel variable in explaining Finnish electricity prices, particularly during this sample period.

Interest rates were highly statistically significant in models two, three, and four, with strong positive coefficients. Thus, in the final model, a one percent increase in Euribor three-month rates would increase electricity prices by 11.248 €/MWh. This suggests that macroeconomic factors such as inflation and financing costs have a significant impact on electricity prices. However, even a one percentage point increase in Euribor rates is a significant change, so it is expected to increase all consumer goods significantly as well. The addition of interest rates to the models decreased the coefficient of EUA prices significantly, which indicates that EUA prices had previously captured variation relating to interest rates rather than pure carbon cost pass-through.

Wind speed was introduced in the third model and was statistically significant, with a strong negative coefficient (-4.383). This implies that a 1 m/s increase in m/s reduces electricity prices by 4.383 €/MWh. This coefficient was the second largest in any of the models. The negative relationship is economically intuitive, as higher wind speeds increase electricity generation using wind energy, which in turn decreases the wholesale electricity prices. This result indicates that wind has a significant impact on electricity markets in Finland. Although wind speed still had a high negative coefficient, it became statistically insignificant in the fourth model after the addition of lagged electricity prices and the date dummy variables. Therefore, it is possible that wind speed was capturing some of the variation related to date variables and previous electricity prices. On the other hand, temperature was statistically significant in model 3 with a strong positive coefficient (1.230) but became statistically insignificant in the final model with a strong negative coefficient of 0.683.

Electricity transmission between Finland and Sweden was statistically significant and slightly positive, while transmission between Finland, Norway, and Estonia was both statistically significant and negative. This indicates that an increase in electricity imports from Norway and Estonia would decrease electricity prices in Finland. Cross-border flows with Sweden had the smallest effect on Finnish electricity prices out of these countries. Transmission from Norway had an especially strong negative impact on electricity prices, with an additional MW decreasing electricity prices by 0.202 €/MWh. Electricity usually flows from Norway to Finland, so this result is consistent with the idea that imports from a low-carbon electricity market reduce domestic prices. Cross-border flows from Finland to Estonia were also negative, although the coefficient is smaller. The dataset for cross-border flows FI-NO was the transmission of electricity between countries, while SE3-FI and EE-FI were commercial electricity flows. This may partly explain why transmission between Finland and Norway had a much stronger effect than cross-border flows with Sweden and Estonia.

The R^2 in the first model, with only EUA prices as the independent variable, was 0.052, indicating that 5.2 % of the variation in electricity prices was explained by this model. The low R^2 was expected, as electricity prices are impacted by multiple factors. With the addition of electricity load, fuel, and energy-mix variables, the R^2 increased significantly to 0.621, suggesting that these variables have a significant impact on the variation in electricity prices. For instance, the addition of cross-border flows and weather variables in the third model led to a more modest increase of R^2 only to 0.643. Finally, the inclusion of lagged electricity price and date dummies increased the R^2 to 0.748, indicating that the final model captured a large proportion of the variation in Finnish electricity prices.

5.2.1 VIF checks

The variation inflation factors (VIF) were calculated after the final regression to evaluate whether there was serious risk of multicollinearity that could have affected the results. Most importantly, the VIF value for EUA prices was 3.76, indicating moderate but not concerning amount of multicollinearity. This suggests that EUA prices were not highly influenced by other control variables. All fuel prices had high VIF scores, which was expected due to the strong co-movement of energy prices during this sample period. Coal had a relatively high VIF score of 10.11 while natural gas was 7.42, indicating moderate to high multicollinearity between the fuel prices. Interest rate variable also had a high VIF (15.78) which is likely caused by close relationship with year dummy variable.

Other variables with high VIF values included electricity load (15.17) and temperature (10.66). This was expected, as temperature has a significant causal relationship with electricity demand especially in Finland due to strong seasonal variation. VIF of electricity load decreased significantly when temperature variable was excluded, confirming the relationship between these variables. Although multicollinearity was present, all variables were kept in the model because of their theoretical relevance. In addition, most variables behaved as expected despite the high multicollinearity. The remaining variables did not have exceptionally high VIF scores. The VIF scores do not unanimously indicate whether a variable should be excluded due to excessive multicollinearity. Since the primary focus of this thesis is the impact of EUA prices on electricity prices, the other variables are included as controls, which makes some level of multicollinearity acceptable.

6 Policy discussion and recommendations

In this chapter, the results of the empirical research are interpreted and discussed in greater detail. The implications of the results are explained, and how the research question of this thesis has been answered. The importance of the study for policymakers and consumers will be explained, and recommendations for future climate policies will be provided based on the insights of this thesis and prior literature. At the end, limitations concerning this thesis are investigated rigorously.

6.1 Further Discussions of Results

EUA prices were the primary focus of the empirical research. The results regarding EUA prices were largely consistent with previous literature. In the final regression with all control variables included, a one euro increase in EUA prices increased the Finnish day-ahead electricity prices by 0.549 €/MWh. This indicates that the increased production costs caused by emission allowances are transferred to electricity prices, which means that consumers bear part of the carbon costs. Prior literature has found the pass-through rate of emission allowance to the electricity prices to range between 60-100 % (Hintermann, 2016; Perrels et al., 2006; Sijm et al., 2006). Although the level-level coefficient estimated in this thesis does not represent a percentage pass-through, it still supports the findings of previous studies that a significant share of emission allowances is transferred to electricity prices.

Emission allowances are statistically significant, and the coefficient is positive, but how much does it impact electricity prices? How significant and impactful are EUA prices in electricity price formation in Finland? In the first baseline regression where EUA prices are the only regressor, R-squared was only 0.052. Based on this result 5.2% of the price variation in Finnish electricity prices were explained by EUA prices. It is still a significant amount but in Finland, due to low-carbon energy structure, there are other factors which are more significant in electricity price formation such as fuel prices and macroeconomic factors.

Out of all the regressions the largest increase in R-squared happened after the inclusion of fuel prices. Fuel prices saw a sharp increase in prices during 2021 and 2022, which may have increased the impact of fuel prices in this empirical model. In Finland during 2024, 2.6% of electricity was generated with coal, 0.94% with natural gas and 0.29% with oil (IEA, 2024). Historically out of these fuel variables coal has had the biggest impact on Finnish electricity prices, however during 2021-2025 natural gas had a much bigger impact. During the period used in the empirical research, fuel prices saw a sharp increase in Europe, especially natural gas prices which lead to an increase in electricity prices also in Finland. Oil prices had a strong negative impact on electricity prices in the empirical model, indicating a strong multicollinearity between fuel variables, which could already be seen in the correlation matrix in Table 3.

The share of wind energy in the electricity mix of Finland has been increasing constantly, and in 2024, it became the second largest source of electricity (IEA, 2024). Wind speed had the biggest negative impact on electricity prices out of all other regressors. Wind speed is a proxy variable for wind energy, so it captured the explanatory power of wind energy, explaining why the wind energy variable had only a small negative impact on electricity prices. The significant negative impact of wind energy suggests that increasing the use of wind energy in Finnish electricity generation decreases electricity prices, which is beneficial not only for businesses and households but also for the climate. This is a great option for Finland, given its climate and potential to harness wind while diversifying the energy mix and strengthening energy security for the future.

6.2 Implications and Recommendations

The empirical results of this thesis and prior academic literature have proved the primary hypothesis that emission allowances increase electricity prices in Finland during the fourth phase of the ETS. Even though carbon-intensive energy sources are barely used in electricity generation in Finland, emission allowances still increase electricity prices. This is due to marginal pricing, as discussed in Chapter 3, which means that the price of electricity is based on the most expensive generator used to match electricity demand. Therefore, during peak demand, Finland might still have to rely on the remaining coal power plants or natural gas, increasing the price of electricity due to the excess use of emission allowances.

The obvious implication of moderate to high pass-through is that consumers bear the main burden of the carbon costs. Carbon-intensive industries account for the largest share of consumers, followed by households and remaining less carbon-intensive industries such as tourism, services, and transport. The 2021-2022 energy crisis could also be seen in residential electricity prices of Finnish households. However, during 2021-2025, the increase in EUA prices explained only a fraction of the increase in electricity prices compared to fuel prices. To alleviate the burden caused by the high cost pass-through of carbon, a consumer protection mechanism should be put in place. The increased electricity prices impact low-income households the hardest, so the protection mechanism should be especially targeted to them.

All, micro, small, medium, and large enterprises are impacted by high pass-through of carbon due to increased electricity prices, which increases production costs. SMEs and large enterprises are also impacted directly by emission allowances because they must incorporate carbon costs into their production costs. Like Finnish households, businesses should also be protected from extreme spikes in electricity caused by the cost pass-through of carbon to maintain competitiveness. In Finland, carbon-intensive industries such as chemical manufacturing and metal industry are subjected to incorporate the cost of EUA prices which increases the cost of production and thereby profits. This may lead to carbon leakage to countries with less strict climate policies which was discussed more in chapter 3.4. The CBAM has already been put in place to deter carbon leakage and protect European carbon-intensive industries from foreign competition. The CBAM is still a new climate policy, so its effectiveness has not been tested yet. Carbon leakage is a very important issue that needs to be addressed in future climate policy because, if ignored it will weaken Europe and Finland economically whilst eroding the purpose of the ETS. The purpose of the emission trading system is to tackle climate change by decreasing pollution, so merely transporting the emissions somewhere else is redundant.

Another implication is that carbon-intensive companies that have received free allowances have made significant windfall profits due to higher EUA prices in phase four. They have passed freely allocated allowances to prices, which has also happened previously, especially during the pilot phase. This should be a sign for policymakers to embark on decreasing freely allocated emission allowances. Although the phasing out process should be done gradually to avoid carbon leakage or eroding the competitiveness of European companies.

On the positive side, the rise in EUA prices incentivizes companies to switch to renewable energy use. In Finland, electricity generation is almost completely carbon-free, which is a testament to Finland's commitment to national and international climate goals as well as the incentives that the ETS has set in place through emission allowances. Although the pass-through rate of carbon is high, it does not equate to the system not working. Power companies still must incorporate the rest of the increased production cost, and although electricity prices are inelastic, in the long-term the demand will shift to companies offering cheaper renewably sourced electricity. In addition, carbon-free companies gain a competitive advantage because they can sell their granted emission allowances while offering cheaper products or prices equivalent to carbon-intensive firms but with lower costs.

6.3 Limitations

The limitations regarding data and methodologies were mostly related to the data aggregation process and the risk of multicollinearity, which were considered during the conduction of the empirical research. However, a more significant limitation to this study was the evaluation of the absolute impact of emission allowances on electricity prices in Finland. This thesis proved there to be high pass-through, but no definitive answer to how much EUA prices increased electricity prices. In 2024, the Finnish energy sector emitted 26.64 $MtCO_2$ equivalents, which converts to approximately 26.64 million emission allowances (Statistics Finland). However, not everything that is included in the energy sector emissions falls under the jurisdiction of the EU ETS, so the number of allowances is lower. According to the IEA (2023), electricity and heating accounted for 8.8 $MtCO_2$, which would convert to 8.8 million emission allowances.

Based on previous findings, these 8.8 million allowances would be passed on to electricity prices quite directly. However, the number of emission allowances in the Finnish electricity sector is relatively small compared to the rest of the EU. The consensus of previous literature is that there is a strong cost pass-through of carbon, but the absolute impact on electricity prices is not clear. Therefore, in future research, the absolute impact of emission allowances on electricity prices, especially in Finland, could be researched more thoroughly.

7 Conclusions

In conclusion, this thesis has demonstrated that emission allowance prices under the EU ETS play a role in influencing Finnish electricity prices among many other factors. The research hypothesis that higher EUA prices would lead to increased electricity prices in Finland was supported by a robust regression analysis, which was in consensus with findings from prior existing literature. One euro increase in EUA prices was associated with a 0.549 €/MWh increase in Finnish day-ahead electricity prices, implying consumers pay a significant share of the increased production cost caused by emission allowances. Therefore, it is crucial for Finnish policymakers to implement strategies to protect consumers, especially low-income households.

The share of carbon-intensive energy sources used in Finland's electricity generation is only 4-5%, but due to marginal pricing, this small fraction still impacts electricity prices during high demand. Therefore, policymakers should aim to cut the use of fossil fuels in electricity generation as soon as possible. This would cut production costs of businesses, save household's income, and overall be better for the Finnish economy. It would also bring Finland one step closer to carbon neutrality.

There is still further research needed to be done to evaluate what is the actual impact of emission allowances on electricity prices. Furthermore, this thesis used daily data to analyse the impact of different price drivers on electricity, but hourly data could give insight into how these variables impact electricity during different times of the day. This is very important information considering electricity prices are extremely volatile within short time periods.

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Appendices

	(1)	(2)	(3)	(4)
EUA	0.459***	0.432***	0.137	0.510***
	(0.140)	(0.138)	(0.138)	(0.195)
Load		2.740***	1.515***	0.157
		(0.171)	(0.368)	(0.419)
Gas		-0.0223	0.0204	0.105
		(0.105)	(0.104)	(0.113)
Coal		1.792***	1.673***	1.364***
		(0.175)	(0.174)	(0.176)
Oil		-1.799***	-1.828***	-1.920***
		(0.244)	(0.241)	(0.264)
Nuclear		-0.339***	-0.401***	-0.252**
		(0.102)	(0.109)	(0.124)
Hydro		0.989***	1.023***	0.781***
		(0.0953)	(0.0947)	(0.0992)
Wind		-0.654***	-0.416***	-0.329***
		(0.0287)	(0.0381)	(0.0428)
EE			0.0000640	-0.0000866
			(0.0000692)	(0.0000848)
SE3			-0.000168***	-0.000233***
			(0.0000522)	(0.0000517)
NO			-0.00539***	-0.00497***
			(0.000775)	(0.000763)
Temperature			-0.0182***	-0.0354***
			(0.00524)	(0.00630)
Windspeed			-0.135***	-0.159***
			(0.0217)	(0.0219)
Weekday FE	No	No	No	Yes
Year FE	No	No	No	Yes
R-squared	0.00632	0.559	0.590	0.615
Observations	1700	1700	1700	1700

Table 5. Log-linear OLS model. Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

	Electricity (€MWh)	EUA (€/tCO2)	Coal (€/t)	Oil (€/bbl)	Gas (€/MWh)	Load (MW)
Electricity	1.00					
EUA	0.25	1.00				
Coal	0.56	0.41	1.00			
Oil	0.36	0.56	0.83	1.00		
Gas	0.66	0.36	0.89	0.65	1.00	
Load	0.13	-0.20	-0.22	-0.20	-0.09	1.00

Table 6. Level-level correlation matrix. Stata.