Aalto University
School of Business

FEED-IN TARIFFS – EFFECTS ON GLOBAL AND DOMESTIC WELFARE

A policy review

Bachelor's Thesis
Toomas Ojala
Aalto University School of Business
Department of Economics
Spring 2023

Aalto University
School of Business

Aalto University, P.O. BOX 11000, 00076 AALTO
www.aalto.fi
Abstract of bachelor's thesis

Author Toomas Ojala

Title of thesis Feed-in Tariffs – Effects on Global and Domestic Welfare

Degree Bachelor of Science in Economics and Business Administration

Degree programme Economics

Thesis advisors Mitri Kitti, Matti Liski

Year of approval 2023 **Number of pages** 26 + 3 **Language** English

Abstract

Feed-in tariffs (FITs) are widely used policies for renewable energy adoption, but their implementation in unsuitable circumstances can result in significant welfare losses for countries. This thesis aims to review existing literature on the welfare effects of FITs at both global and domestic levels and compare them to a comparable international emissions trading system. Previous research has focused on examining emissions offsetting and domestic externalities of renewable energy production separately, and there is limited research on analyzing these aspects together. Therefore, this thesis provides a summary of the latest literature on these topics to assist policymakers rationalize whether to consider implementing FITs as a means of subsidizing renewable energy.

The current literature suggests that implementing FITs may result in higher emissions offset costs compared to an international emissions trading system, leading to global welfare losses. While domestic renewable energy production generates positive externalities that could potentially offset the higher compensation costs of FITs, the cost difference is substantial and may not be fully offset by these positive externalities. Therefore, policymakers must carefully evaluate whether the potential net positive externalities are significant enough to justify the higher costs of FITs compared to emissions trading systems. This may only happen in countries with a high marginal utility for externalities and the necessary expertise to optimize policies by prioritizing the externalities with the greatest benefit-to-cost ratios.

Keywords feed-in tariff, emissions trading, CO2 emissions, welfare efficiency, externalities

Table of Contents

1 Introduction

The long-term effects of climate change make it a significant threat to humanity with far-reaching consequences for the economy. The release of greenhouse gases into the atmosphere is the main contributor to climate change, with non-renewable energy sources being the main contributor as a form of energy production. (Höök et al., 2013) Governments around the world have begun to adopt various strategies to minimize the risks of climate change, including reviewing their energy policy interventions and strategies (Olabi et al., 2022). Globally, this means a huge distribution of public funds to stakeholders driving technological development and renewable energy generation.

Policy interventions refer to government actions aimed at regulating or influencing the behavior of individuals, firms, or other economic agents to achieve specific economic goals. It is widely recognized in economic theory that individuals do not take into account the external costs and benefits of their actions, which can lead to market failures and suboptimal outcomes. This is particularly relevant when negative externalities are involved, such as the release of greenhouse gases, which can have significant environmental and public health impacts. In such cases, government intervention is seen as a critical tool to mitigate climate risks and achieve a socially optimal outcome. Feed-in tariffs (FITs) are widely used policy instruments to incentivize investment in renewable energy and serve as a means to offset greenhouse gas emissions. The policy provides agreements for renewable energy providers to purchase their energy at a predetermined price system. By 2008, the FIT policy had enabled the deployment of about 75% of the world's solar photovoltaic (PV) and 45% of its wind energy capacity. By 2011, these regulations had been implemented in over 87 countries worldwide. (Alizamir et al., 2016) This thesis examines the possible welfare losses that the world and individual countries may have faced due to its historical implementation.

1.1 Research question

The literature review focuses on the following research question:

Are feed-in tariffs a welfare-efficient solution for offsetting greenhouse gas emissions at a global and domestic level?

Carbon tax such as emissions trading system is still considered to be one of the most efficient policy measures to offset carbon emissions (Gugler et al., 2021). For example, Reguant (2019) studied Californian electricity markets and concluded that offsetting emissions via a carbon tax is notably cheaper than directly subsidizing technologies such as solar and wind energy. The adoption of policies that come with higher costs may result in inadequate net expenses for taxpayers, ultimately leading to welfare losses. Given this concern, this thesis reviews recent literature on FITs to evaluate their potential welfare effects and assess their suitability for future implementation. I first review the matter from the perspective of global welfare and establish the welfare effects compared to a carbon tax system solely focusing on the offsetting potential as was done in the work of Reguant (2019). However, FIT policies are primarily implemented at the country level, which is heavily impacted not necessarily by individuals' self-interest (Feldman 1982), but by the interest of domestic welfare maximization. Therefore, assessing the welfare effects of a policy through a domestic perspective holds greater strategic relevance for policymakers that most likely seek to optimize domestic welfare. Consequently, countries may prioritize policies that optimize their domestic welfare, even if they may not necessarily align with global welfare optimization.

This thesis has identified and addressed several challenges within the research setting. Notably, the country-specific nature of FITs limits the generalizability of findings due to variations in country economics and the policy implementation timeline. Additionally, the welfare effects of FITs have been examined from two perspectives, each utilizing stylized concepts that may overlook certain welfare effects. For example, global welfare accounts only for the costs of emissions offsetting overlooking possible changes in welfare benefits depending on how the energy supply is distributed and what technologies are subsidized. Furthermore, the current literature provides limited findings on the domestic externalities of FITs. Therefore, while the thesis proposes that domestic externalities have a net positive impact, this assertion lacks definite empirical validation. Finally, it is crucial to acknowledge that this thesis employs an emissions trading system as a benchmark, which also has its potential drawbacks such as the risks of carbon leakage, allowance misallocation, and the lack of consideration for the welfare changes associated with emissions beyond CO2. Therefore, any comparison between FITs and emissions trading systems must be approached with caution to prevent biased conclusions.

This thesis examines the fundamental theory of FITs and international emissions trading using the works of Couture et al. (2010) and Babiker et al. (2004), respectively. These concepts serve as the basis for the ensuing arguments, which are supported by economic theory. Specifically, the thesis begins by reviewing the research conducted by Dijkgraaf et al. (2018) and Dong et al. (2021) to examine whether FITs promote investment activity in renewable energy, and thus, create welfare effects. Furthermore, the thesis explores the welfare effects of FITs at both the global and domestic levels by analyzing the costs associated with emissions offsetting through FITs and the externalities that result from the creation of renewable energy in domestic markets. To assess global efficiency, the thesis draws upon empirical studies conducted by Bakhtyar et al. (2014), Abrell et al. (2019) and Gugler et al. (2021), which primarily focus on solar photovoltaic (PV) and secondarily on wind energy in Germany and China. To evaluate the domestic welfare effects, the thesis reviews studies such as Andini et al. (2019), which analyze the macroeconomic impact of these externalities, and Zerrahn (2017), which highlights the significance of energy security. By synthesizing these various perspectives, the thesis seeks to provide a comprehensive evaluation of the welfare effects of FITs.

The thesis finds that FITs can effectively promote new renewable energy production which then leads to costs for a country. To improve the policy's welfare efficiency at both global and domestic levels, policies should be tailored to address and utilize country-specific characteristics. Compared to emissions trading systems, FITs may be a more expensive policy to offset emissions, resulting in global welfare losses. However, FITs can create positive domestic externalities that an emissions trading system cannot. Due to limited empirical research, the magnitude of these externalities is unclear, and their precise effects cannot be determined. In rare cases, these externalities may justify the significant cost difference between FITs and emissions trading systems. Nonetheless, most implemented FITs have also led to domestic welfare losses.

This thesis is a literature review that explores the welfare effects of feed-in tariffs at a global and domestic level. The thesis is structured as follows. Chapter 2 explains what feed-in tariffs are. Chapter 3 presents the theoretical background for free allocation and welfare. Chapter 4 provides a comprehensive review of the existing literature on the topic. Chapter 5 discusses the findings, and Chapter 6 concludes.

2 Feed-in tariff

The underlying principle of the feed-in tariffs (FIT) policy is to offer financial incentives for renewable energy production through predetermined pricing and contract duration. This approach provides attractive returns for investors and enables reliable projections of future cash flows, allowing for adequate compensation for the expenses incurred in developing renewable energy projects. The FIT framework is capable of supporting various technologies at different stages of development, with pricing that aligns with the productivity of a particular technology. Typically, FIT contracts have durations ranging from 8 to 30 years. (Couture et al., 2010; Lipp, 2007)

FITs should be built on a case-by-case basis utilizing frameworks that complement a country's characteristics. One key factor that distinguishes such policies is whether they are dependent on the market price of electricity. (Klein et al., 2008) In this thesis, I introduce the most common framework of FITs proposed by Couture et al. (2010), where the price is detached from the market price. This model is known as the Fixed price model (Figure 1), which offers a constant purchase price over the duration of the contract. The design ignores factors such as inflation that tend to gradually reduce the real value of the payment. Estimating these changes can result in payments that are much higher or lower than necessary. Nevertheless, it is not uncommon for the retail price to be lower than the FIT price throughout the contract term due to high historical FIT prices.

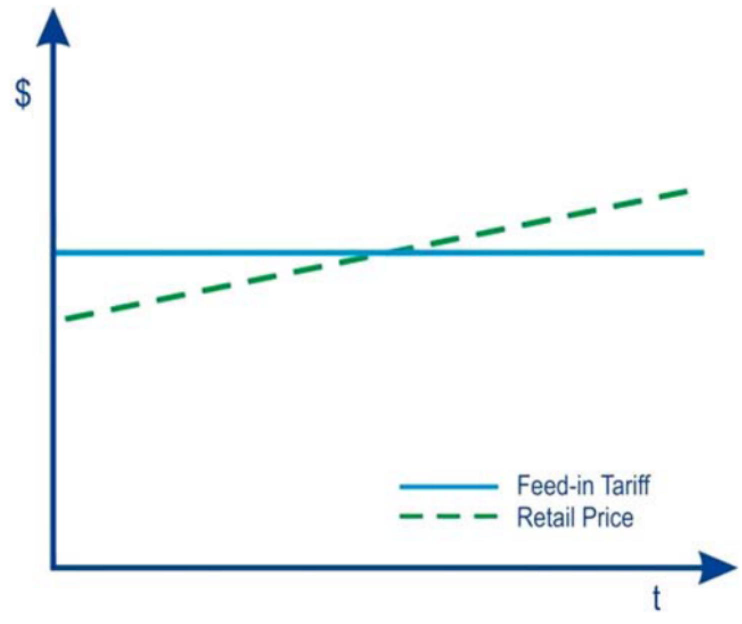

Figure 1. Fixed price model (Couture et al., 2010)

3 Theoretical framework

3.1 International emissions trading

In the following chapter, I will rationale for using the international emissions trading system as the alternative measure for FIT. I will also discuss the potential drawbacks of this solution.

It is widely recognized in economics that individuals do not take into account the external costs and benefits of their actions, which can lead to market failures and suboptimal outcomes. Therefore, government intervention is often necessary to internalize externalities and achieve economic efficiency. Economists largely favor the use of transferable emission permits, relying on market forces to find welfare-efficient ways to offset emissions. By doing this authorities can focus only on issuing the optimal quantity of emission allowances rather than betting on the winning technologies, tariff prices, and geographic locations. (Babiker et al., 2004)

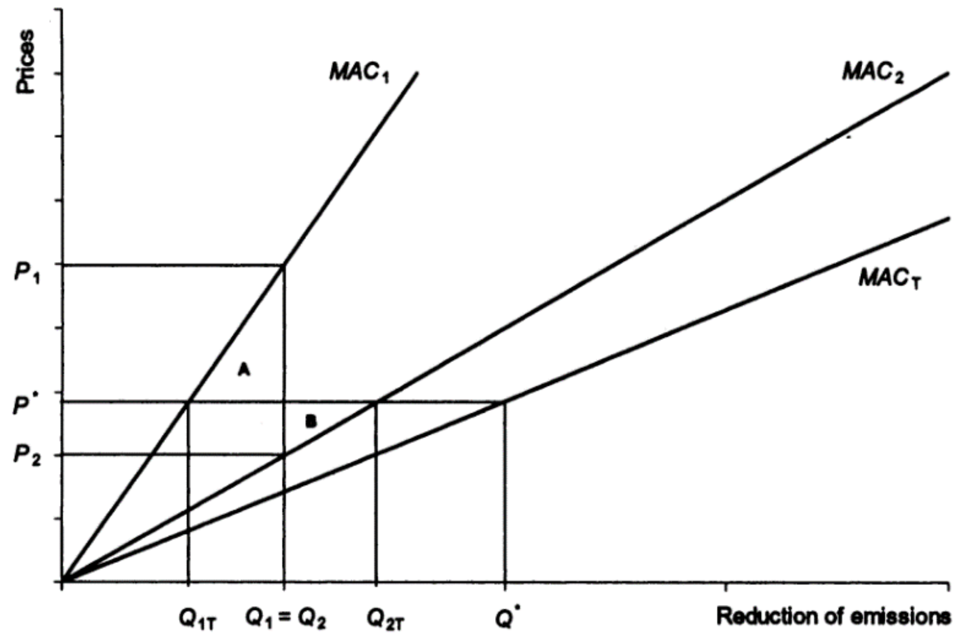

Figure 2. Cost-effectiveness of international emissions trading (Babiker et al., 2004)

The cost-effectiveness of international emissions trading can be illustrated by a graphical comparison between two countries firstly offsetting their own emissions, and then moving to the international emissions trading system. Babiker et al. (2004) illustrate this framework in a distortion-free world, where Figure 2 presents the marginal cost of offsetting emissions for two countries: MAC_1 for Country 1 and MAC_2 for Country 2. In the first situation without emissions trading, the total quantity of emissions reduced is equal between the countries, which are both found in $Q_1 = Q_2$. Country 1 incurs a marginal cost of P_1 to offset emissions quantity Q_1, whereas Country 2 has a much lower marginal cost of P_2 for the same quantity Q_2.

The international emissions trading system is now set up so that the MAC_T reflects the marginal offsetting costs of the two countries in aggregate. The quantity of emissions offsetting for the two countries is Q* (adding Q_1 and Q_2 together) with a price of P*. Now both countries reduce emissions until their marginal cost of emission reduction (MAC_1 for Country 1 and MAC_2 for Country 2) equals the international cost of emission reduction P*. Country 1 decreases its offsetting amount from Q_1 to Q_{1T} and buys the reduced difference from Country 2 with a welfare gain A. Country 2 increases its offsetting amount from Q_2 to Q_{2T} and sells the excess offsetting contracts to Country 1 with a welfare gain B. The total welfare has increased by A + B and an efficient outcome is achieved since the total emissions are offset with the lowest possible costs.

The European Union Emissions Trading System (EU ETS) operates in Europe with the same pricing mechanism as described above, but policymakers determine the quantity that every company is allowed to pollute. The mechanism establishes a market-based pricing system for tradable emissions allowances, which can be bought from the market instead of the government paying for emissions offsetting via FITs. The literature has expressed concerns regarding the efficiency of such pricing mechanisms due to the potential risk of carbon leakage. When the competitiveness of a region is affected due to an increase in production costs caused by location-specific policies, the risk of carbon leakage arises. This happens when production is relocated from a regulated area to an unregulated one due to a shift in relative competitiveness. (Naegele et al., 2018)

Carbon leakage can lead to significant emissions mispricing, as the relocation of businesses reduces the demand for pollution permits, leading to a price decline within a basic supply-demand framework. It is crucial to acknowledge that the EU ETS is an evolving system, and significant alterations have been implemented since its inception in 2005. It is expected that the system will adapt over time and fix the potential problems that may lead to mispricing. For example, the Council of the European Parliament reached a political agreement to implement a system called the Carbon Border Adjustment Mechanism in 2023 to address the problem of carbon leakage (Taxation and Customs Union, 2023). Furthermore, Nordhaus (2016) revisited the social cost of carbon that the price of EU ETS should reflect for an economically efficient outcome. According to his calculations, the estimated cost of the negative environmental impact of carbon emissions is between 30-100 US$ per ton of CO_2. This estimate is consistent with the price of carbon in the EU ETS, but only after 2020 which is mostly out of the current literature's data. This suggests that the EU ETS prices may not be a good benchmark before the year 2020.

There is an economic rationale for comparing FITs to international emissions trading systems such as EU ETS. However, it is important to understand how the international emissions trading system works to use it as a point of comparison with FITs, as it is not an infallible tool in an uncertain world. The limitations are further analyzed in Chapter 5.

3.2 Welfare effects

In this chapter, I discuss how the thesis interprets the welfare effects of FITs from two different perspectives: global welfare and domestic welfare. The welfare effects of FITs vary depending on the perspective considered in comparison to international emissions trading systems, and these variations will be further examined next.

3.2.1 Global welfare

In the thesis, the term "global welfare" refers to the welfare of all countries as a whole. Greenhouse gas emissions have a negative impact at the global level. To address this issue, taxpayers' money has been used by implementing FITs to counteract the negative externalities. However, if the same amount of emissions could have been offset with less money, FITs may have created inefficiency losses at a global level. Therefore, I draw a comparison between the emissions offsetting costs of FIT and an international emissions trading system, which is highly regarded as one of the most cost-effective methods of offsetting emissions by economists. Global welfare analysis overlooks other costs and benefits apart from emissions offsetting due to the lack of a reasonable counterfactual that is needed to consider the welfare changes of energy distribution and technology subsidies. For example, the thesis overlooks the global welfare effects of R&D by FITs, which may give net welfare gains when compared to the emissions trading system. However, given that the two schemes typically coexist, the increased emissions offsetting capacity provided by FITs may reduce the allowance prices of an emissions trading system. Moreover, the price reduction may influence the market-induced R&D incentives, and thus, have also a negative welfare effect on global R&D.

3.2.2 Domestic welfare

The term "domestic welfare" refers to the welfare of individual countries within an international emissions trading system. Belonging to the system implies that these countries are committed to fulfilling their respective roles in offsetting emissions, thereby avoiding the free-rider problem of climate change actions.

Countries implementing FITs encounter domestic externalities that have the potential to positively impact their domestic welfare. Hence, it is essential to consider these externalities when evaluating FITs' impact at a domestic level. The existence of net positive domestic externalities provides policymakers with a greater incentive to adopt FITs since they generate additional welfare benefits beyond offsetting global emissions. This perspective should be the primary focus for policymakers seeking to maximize domestic welfare. For a FIT to be considered a more welfare-efficient choice than an emissions trading system, the net externalities must offset all possible cost differences between a FIT and the international emissions trading system. It is assumed that no domestic externalities arise from the international emissions trading system as the cleaner production deployed by market-based mechanisms typically takes place overseas, leading to zero domestic externalities (Ang et al., 2015; Rosenthal et al., 2008). If cleaner production would take place domestically, it remains uncertain what form of energy production will substitute the polluting one, thereby affecting the magnitude of externalities.

4 Literature review
4.1 Attracting investments

FITs compensate renewable energy suppliers based on their energy produced to the grid. Thus, the economic impact of FITs arises primarily when domestic energy is produced. In this chapter, I review four papers on FITs' capability of creating new renewable energy production.

Dijkgraaf et al. (2018) researched the development of solar PV in OECD member countries between 1990 and 2011. Their results revealed that a well-designed FIT could have a significantly greater impact on promoting renewable energy adaptation than a poorly designed one. Their model demonstrated that the average increase in solar PV capacity per resident was 5.5 Wp (watt-peak), while the sample average was 5.1 Wp indicating the massive role of FIT in the adaptation of solar PV technology in OECD countries. The average effects of FITs in the existing literature underestimate the true potential, as better designs can lead up to seven times greater results when sampling the most proven designs. To enhance the internal validity of their findings, the model controlled the influence of other policies and adjusted for country-specific power generation structures and CO2 emissions levels. Nonetheless, the results should be cautiously used when extrapolating the findings to the post-2011 period, given the decline in the cost of solar PV deployment since then. Despite this limitation, this study provides crucial insights into the potential effectiveness of FITs as a policy tool for promoting renewable energy adaptation.

In China, two neighboring zones have different FIT policies. Dong et al. (2021) estimate the impact of FIT incentives on solar PV capacity development between 2013 and 2019, estimating that a 0.1 yuan/kWh ($0.014/kWh) increase in subsidies adds about 18 GW/year of installed capacity to the domestic solar PV market. The results of the study are in the middle of previous estimates in China and address the factors that led to biased estimates in previous studies. The previous estimates at the low and high ends are about 140 times smaller and 16 times larger than the estimates of Dong et al. (2021). The credibility of the paper is enhanced by eliminating the biases of previous studies and by providing results that more accurately reflect the historical deployment of solar PV in China. Furthermore, the quasi-experimental design utilized in the study enhances the credibility of the result's causality.

According to Ndiritu et al. (2020), FIT has not contributed to renewable energy generation in Kenya. A decade after its introduction, FIT-driven renewable energy production is only at 10 MW, far from the 1551 MW target. Although the policy has stimulated investment interest, its implementation has been significantly delayed, mostly due to insufficient technical expertise. Most of these FIT projects are still in the earlier stages of the development process, suggesting that implementation is slow with recurring bottlenecks during the development process. The main limitation of the study was the limited population of private sector projects, resulting in the lack of quantitative analysis of the case.

While the existing literature has sufficiently addressed the optimal designs of FITs, it is critical to assess the unique bottlenecks in each country to ensure that FITs can be used effectively as intended. In general, FITs have been successful in promoting new investments in recent decades, resulting in increased renewable energy production. However, the effectiveness of FITs depends on how well domestic issues are addressed, and the amount of new capacity is a tradeoff between costs and the amount produced, where an increase in FIT rates appears to be associated with a greater amount of capital invested. For more results supporting the ability of FITs to promote renewable energy production, see Del Río et al. (2007) and Mah et al. (2021).

Now, I have concluded that FITs have been successful in promoting domestic renewable energy deployment in the past, leaving governments to pay the money for producers. This means that FIT-induced production has welfare impacts at the global and domestic levels.

4.2 Global efficiency

This section aims to examine the current literature on the global welfare effects of FITs around the world. Callaway (2017) argues that policy efficiency is achieved when policy subsidies properly account for the external costs and benefits of renewable energy projects so that funds are efficiently distributed across technologies and regions. In terms of global welfare, the section compares the costs of emissions offsets between FIT and the emissions trading system. A more detailed explanation of global welfare can be found in Chapter 3.2.1.

Bakhtyar et al. (2014) review solar PV FIT policies in thirteen countries across five continents. Their objective is to evaluate the expenses associated with offsetting CO2 emissions. They create an indicator called Substitute Price of Avoiding C02 Emissions (SPAC), which calculates the cost of avoiding the emission of one ton of C02 in a given country. The results assess the offsetting costs by establishing variables such as the type of energy sources used, the cost of the technologies, and the subsidies provided by the government. A low SPAC value means that a country can offset C02 emissions at a lower cost, while a higher SPAC value indicates a more expensive cost to compensate for C02 emissions in the country. It is important to note that SPAC is based on the assumption that newly generated renewable energy replaces a more polluting energy source, which may not be always the case.

	Cost of producing
Country	US$/ton C02
Peninsular Malaysia	660
Thailand	424
Japan	1099
Germany	745
Greece	893
France	7114
Ontario (Canada)	4149
Vermont (US)	502
Victoria (Australia)	1111
Ecuador	2162
South Africa	382
Argentina	449

Table 1. Countries' payment for offsetting one ton of C02 emissions by solar technology (Bakhtyar et al., 2014)

Table 1 presents the SPAC results per country. During the implementation of the policies, the emissions trading system (EU ETS) was priced at around 40 €/ton of CO_2. As a result, Table 1 results show that the costs of offsetting emissions through FITs were considerably higher in all the countries studied compared to the alternative measure. France has a SPAC value of 7114 US$ per ton of C02 emissions, which means that on average the country has paid 7114 US$ through solar PV FIT to offset one ton of C02 emissions. This number is particularly high in France because the country generates a significant amount of its electricity from nuclear power plants that produce very low levels of C02 emissions, making the cost of avoiding the country's remaining carbon emissions extremely high. As in France, the calculation ignores other problematic emissions than greenhouse gasses, making it insufficient for evaluating the transition away from non-C02 emitting energy sources.

A study by Abrell et al. (2019) evaluates solar and wind FITs in Germany and Spain. They find that the cost of reducing carbon emissions through renewable energy measures varies widely by technology. Depending on the assumptions made regarding foreign carbon offsets, the cost of reducing a ton of CO_2 emissions through solar FITs in Germany and Spain can range from 411-972 € and 784-1944 €, respectively. In contrast, the cost of reducing CO_2 emissions through wind FITs in the German market is much lower, at 105-276 € per ton of CO_2, which is approximately one-fifth of the cost of reducing CO_2 emissions through solar. In Spain, offset costs for wind energy subsidies are somewhat lower, ranging from 82-258 € per ton of CO_2. Due to limited data availability, the paper had to rely on assumptions about international carbon offsets. While the lower range of wind energy costs in both countries suggests a degree of promising outcomes, the considerable spectrum in cost estimates raises questions regarding the feasibility of these scenarios.

Gugler et al. (2021) use a natural test environment to compare the effectiveness of two carbon reduction policies: pricing carbon emissions and FITs for solar and wind power. The study examines and contrasts the electricity sectors of Germany and the UK, which share similarities but employ distinct policy approaches. Specifically, Germany employs a FIT to incentivize renewable energy production, while the UK utilizes a country-specific carbon price support policy on top of EU ETS allowances, with the premium incrementally increasing the cost of the allowances. According to the research, the implementation of a carbon pricing mechanism proves to be more efficient in offsetting emissions than subsidizing renewable energy generation via a FIT system. However, the success of the carbon pricing approach depends on whether the carbon price is sufficiently high to drive the shift towards cleaner production practices, which is estimated to be around 30 € per ton of CO_2 emissions. The study also reveals that renewable energy subsidies and carbon pricing can either complement or hinder each other, depending on the specific technology being replaced. In Germany, wind and solar energy become more attractive when the carbon price rises to replace coal. Nonetheless, in the UK, where policy incentives have already caused the carbon price to rise, wind energy would replace gas instead of coal. This transition may lead to higher future compensation costs, attributable in part to the adoption of cleaner technologies and the alteration of pollution quality, as was seen in high SPAC values in France by Abrell et al. (2019).

Dong et al. (2021) studied the cost-effectiveness of FIT-induced solar PV in China between 2013-2019, currently the largest market for solar PV deployment in the world. According to their results, the average offsetting cost of FIT is 123 yuan per ton of CO2 emissions (US$17,2/ton), while the comparable emissions trading price in China was 20-50 yuan/ton. They suggest that FITs may not be a cost-effective tool for offsetting C02 emissions in China because of the cheaper alternative, and solar PV would almost totally disappear without policy intervention. The differences in offsetting costs of FITs between China and European countries are primarily because highly polluting coal accounted for nearly 64% of China's energy mix in 2015 (Qi et al., 2016), making the replacement of polluting technology more effective in terms of offsetting emissions.

In the empirical literature, estimates of FITs' offsetting costs vary widely depending on the research setting, country and period, but they all reach the same conclusion: most FITs have not been globally welfare-efficient tools for offsetting C02 emissions. The results suggest that the degree of inefficiency is many times higher than the offsetting costs via a comparable emissions trading system. There are also some indications that the costs of emissions offsetting can vary widely by technology.

4.3 Domestic efficiency

Currently, there is a limited amount of empirical research that covers domestic externalities by FITs. This section aims to examine the most relevant findings regarding the domestic externalities stemming from newly produced renewable energy and to evaluate whether FITs can generate net positive domestic welfare effects. A more detailed explanation of domestic welfare can be found in Chapter 3.2.2.

Since private companies participate in the international emissions trading system, actions aimed at benefiting individual firms may not necessarily yield a net benefit for the entire country (Babiker et al., 2004). As previously discussed, countries should review FITs from the perspective of domestic welfare to maximize domestic welfare. To determine whether a FIT produces welfare gains at a domestic level relative to the emissions trading system, the net domestic benefits must be large enough to offset the difference between a FIT and an emissions trading system.

4.3.1 Macroeconomics and energy security

Research on the macroeconomic impact of FITs is limited. Andini et al. (2019) shed light on how renewable energy generation projects affect macroeconomic factors in Portugal. They conducted an empirical study using macroeconomic data from 1977 to 2015 and found that the investment phase yields transitory benefits, while the operational phase has more permanent benefits to the economy. Moreover, both phases have a positive impact on real GDP growth, even though inflation rates tend to increase slightly. The increased GDP growth during the operational phase is attributed to the reduction in net energy imports as a share of GDP. The outcomes imply that renewable energy initiatives hold the potential to aid in achieving local and regional policy objectives by decreasing unemployment and augmenting GDP growth in areas that require such results. As a result, they can serve as a type of expansionary fiscal policy. The external validity of this paper is once again questionable due to the time- and country-specific implementation of FITs. However, these effects have been analyzed with a relatively large data set and clear macroeconomic benefits have been found that seem to be promising for other countries as well.

The implementation of FITs stimulates the growth of domestic energy production, which in turn can reduce a country's dependence on imported non-renewable energy and reduce reliance on a few dominant suppliers that have significant market power. In addition, diversification of energy transportation routes would also help achieve this goal. Decentralization of power generation through government initiatives can reduce vulnerability to macroeconomic supply shocks, physical attacks, or technological failures. Furthermore, renewable energy sources generally provide distinctive domestic benefits owing to their non-depletable nature, in contrast to fossil fuels. (Zerrahn, 2017) Energy security creates positive welfare effects for a country, which should be valued in decision-making. If a country has a limited domestic energy supply or is located in a politically unstable region, improving energy security can provide greater positive benefits due to the higher marginal utility of each energy unit produced.

Dong et al. (2021) find that in China, regions with relatively high electricity demand are more encouraged to develop FIT-subsidized solar PV production – the study does not provide a definitive explanation for this observation. Investors are typically driven by a desire to find the best risk-reward ratio. This ratio may be most attractive in regions of high demand, as higher deployment volumes lower the price less in regions of high demand. On the other hand, higher demand may lead to a more inelastic demand curve, so producers are more likely to earn higher returns in the event of supply and demand shocks. Thus, FITs may have the ability to allocate efficiently at the domestic level and provide energy security in the regions where they have the greatest benefits in terms of energy security. This implies that while the primary objective of investors is not to allocate energy production efficiently, their investments may have additional microeconomic benefits in an efficient domestic renewable supply allocation.

4.3.2 Learning spillovers and patents

The construction of new renewable energy facilities leads to a concentration of skilled workers in a given area, which according to economic theory can lead to learning spillover effects. Bollinger et al. (2019) studied these externalities at solar PV plants in California between 2002 and 2012 and found evidence of learning spillovers. According to their estimates, learning was more significant in the early years of the period studied, and they observed that knowledge was passed from one firm to another in PV installation, decreasing costs over time. This may indicate that marginal learning spillovers are strongest in countries where the technology is new. The study used a large data set with a variety of control variables, which increases its internal validity. However, Rubin et al. (2015) examined learning rates in energy production technologies and discovered notable variations in learning. Learning rates refer to a marginal decrease in the cost of energy production that occurs for each doubling of total capacity. In some countries, such as the UK, the learning rate was 25% between 1991 and 1999, while in Denmark it was roughly 7% over the same period. The paper notes that the variability cannot be fully explained by systematic differences in the controlled variables of the study, which decreases the internal validity of the learning spillovers.

Ma et al. (2021) argue that subsidies promoting economies of scale can decrease solar PV costs via increased local learning, yet their impact is inferior to the long-term potential of

R&D investment. They find that in solar PV the way the scheme is designed influences investors' willingness to invest in R&D, making the overall impact depends on how FIT is implemented. This would suggest that the scheme could be tailored to promote some of the externalities with the greatest benefit-to-cost ratio. Recent studies show that European FITs boost innovation in the policy-setting country, especially for high-value patents in solar and wind energy. Although wind is confined to its field, solar and storage tech developments benefit other sectors too. (Böhringer et al., 2017; Lindman et al., 2016; Noailly et al., 2017) The results indicate that countries that do not implement technology-enhancing policies with suitable deployment strategies may not observe such effects. In contrast, Acemoglu et al. (2014) have demonstrated that a superior approach to carbon taxation involves the implementation of research subsidies on top of the system. Although the benefits obtained from this system may compete with those of R&D induced by FITs, it should be noted that such benefits are realized only after incurring additional costs associated with subsidizing research.

4.3.3 Physical effects

The potential health effects should be considered when planning the domestic energy supply. According to Armstrong et al. (2016), the combustion of non-renewable energy sources has significant public health implications, with nearly 40% of the world's population exposed to the resulting air pollution. The extent of health benefits from cleaner energy production varies by the country studied. Factors such as population density, meteorological conditions, and average emissions generated by the current power grid influence differences in external costs associated with polluting technologies. This leads to significant differences between developed and developing countries, as noted by Bielecki et al. (2020). The study states that health impacts are primarily related to population density in affected regions and that the amount of damage per unit of pollutant emitted is highly dependent on the location of the emission source and the physical characteristics that affect the dispersion of pollutants. Quantifying the value of human lives and healthcare costs is critical when evaluating the benefits of replacing technologies that have serious local pollution effects, such as lower air quality.

There is a general concern about the negative externalities resulting from noise and visual impacts of wind energy. However, according to Zerrahn (2017), there is no conclusive evidence of causal health effects caused by noise generated by wind energy. Regarding the visual impacts of renewable energy generation, Mattmann et al. (2016) argue that each renewable energy source has its unique characteristics that need to be evaluated in terms of the net visual effects they generate based on the technology and location used. Dröes et al. (2016) highlight the complexity of these externalities. According to their empirical results, a wind turbine located within a 2 km radius of a residential area can cause a 1,4% decrease in the value of nearby homes. However, it should be noted that property owners on whose land wind turbines are erected often receive compensation from the turbine owners. Therefore, a comprehensive assessment of welfare effects should consider not only the negative impacts on property prices but also the potential benefits of compensation to landowners.

4.3.4 Domestic efficiency overview

The lack of empirical research on aggregate domestic externalities limits the assessment of the FITs' ability to create domestic externalities. Nevertheless, the results imply that domestic externalities are dominated by benefits rather than costs. If the net externalities are positive, FITs may be more economically efficient than an emissions trading system, thereby increasing domestic welfare. However, current empirical research does not suggest any groundbreaking quantity of domestic externalities that would be required to offset the several times higher costs of FITs compared to an emissions trading system.

Next, I demonstrate the scale of domestic externalities per ton/C02 required based on the research of Bakhtyar et al. (2014) regarding the offsetting costs induced by FITs on German solar PV:

FIT[1] = cost of FIT per ton/C02 emissions
ETS[2] = EU ETS
E = domestic externalities

[1]Germany solar PV abatement cost from USD to EUR (Bakhtyar *et al.,* 2014)
USD to EUR in the year 2013 average:
745$/1,3281 ≈ 561€
https://www.suomenpankki.fi/fi/Tilastot/valuuttakurssit/taulukot/valuuttakurssit_taulukot_fi/valuuttakurssit_long_fi/
[2]EU ETS (Bakhtyar *et al.,* 2014)

I calculate the required externalities to achieve cost parity between FIT and EU ETS.

$$\mathrm{FIT}^1 - \mathrm{E} = \mathrm{ETS}^2 \tag{1}$$

$$561 - \mathrm{E} = 40 \tag{2}$$

$$\mathrm{E} = 521 \tag{3}$$

Net positive externalities per ton/C02 emissions should be 521 €. Using this value, I determine the ratio of required externalities to EU ETS.

$$\frac{\mathrm{E}}{\mathrm{ETS}^2} \tag{1}$$

$$\frac{521}{40} \approx 13 \tag{2}$$

According to the findings of Bakhtyar et al. (2014), the externalities per ton/C02 should have been 13 times larger than the overall offsetting costs through the emissions trading system EU ETS.

5 Discussion

Before conclusions, I will discuss what the empirical evidence suggests about the welfare efficiency of FITs at the global and domestic levels. Then I will assess the external and internal validity of the results.

The empirical findings suggest that FITs have successfully promoted renewable energy production so that welfare effects are created. The findings indicate that FITs are not the most cost-effective approach for offsetting CO2 emissions, leading to efficiency losses at the global level. While research on domestic externalities is limited, existing literature suggests that positive externalities outweigh the negative ones domestically. Therefore, while FITs may be more expensive than emissions trading systems on a global scale, they may be more welfare-efficient domestically if the externalities can compensate for the cost difference. However, since the cost of offsetting emissions through FITs is significantly higher than emissions trading, substantial net positive domestic externalities would be necessary for FITs to be preferred as demonstrated in Chapter 4.3.4. Therefore, without additional research, it is difficult to argue for the welfare efficiency of FITs either globally or domestically.

Since individual countries consist of complex, multi-layered entities, it is evident that no two countries are alike. Thus, the design of FITs must be tailored to country-specific challenges to achieve new production in a more cost-effective manner that most likely has positive welfare effects at the global and domestic levels. This is because a reduction in the cost per MW of electricity generated by the government will reduce carbon offset expenditures and make the benefits achieved from externalities more affordable. A well-designed system should target the externalities with the largest marginal utility for a particular country. An example of such a scheme might be a region-specific program aimed at enhancing energy security in strategically critical areas that derive significant benefits from secured energy production.

The utilization of results across different countries poses several challenges. The assessment of offsetting costs for FITs can exhibit significant variations across countries as estimates usually rely on country-specific factors. For instance, as reviewed in Chapter 4.3.2, Rubin et al. (2015) find significant cross-country differences in learning rates of electricity-producing technologies, which highlights the scale of potential variation in domestic externalities. Despite the presence of imperfect data, utilizing empirical results is crucial for achieving the most accurate outcomes. The precision of the estimates can be improved by utilizing the most recent empirical research setting that closely aligns with the economy of the policy-setting country. Furthermore, the results of domestic externalities presented in this thesis suggest that FITs can be tailored to boost specific domestic externalities. This means that prior evidence can be leveraged to determine and prioritize domestic externalities that offer the most favorable benefit-to-cost ratios in the policy-setting country, which may not vary as significantly as the quantitative magnitude of externalities.

The considerable rise in the value of carbon allowances within the EU ETS since 2020 indicates a noteworthy change in market dynamics that has yet to be incorporated into existing studies. The increase in allowance prices leads to higher polluting costs and greater incentives for renewable energy generation. In the short-term increased allowance prices reduce the cost difference between a FIT and an emissions trading system, which increases the probability that externalities will offset the cost difference. On the other hand, as presented in Chapter 4.2 (Gugler et al., 2021), the allowance price of 30 € ton/CO2 has already led to a significant transition from polluting energy production to cleaner alternatives. Consequently, the significant increase in allowance prices of EU ETS may prompt a substantial surge in the investment interest and deployed quantity in the future for renewable energy sources. The surge in investment interest will increase investment costs for all the investors forcing countries to raise their tariff prices to match previous levels of investment interest, thereby elevating the costs of emissions offset via FITs. Furthermore, the existence of a market-based carbon tax system (EU ETS) has incentivized economic players to less-polluting energy production, which may reduce the emissions offsetting potential by FITs as new production replaces fewer polluting technologies. As such, it remains unclear which effect will dominate in the long term, which will determine changes in the relative costs between FITs and emissions trading systems.

In addition to the carbon leakage already discussed in Chapter 3.1, the international emissions trading system may have other problems that weaken its performance as an alternative measure. If authorities release allowances beyond what is considered socially optimal, it results in an oversupply of carbon permits, leading to an undervaluation of the social cost of carbon. In such a scenario, deploying a FIT would probably prove to be more welfare-efficient than what has been proposed in this thesis. This is because the socially optimal price is higher, which leads to a reduction in the difference between the policy costs. On top of this, the implementation of FITs leads to an increase in welfare by addressing the market failure to incentivize adequate renewable energy production that is now partly created by FITs. It is critical to recognize that undersupply, on the other hand, would make FITs less efficient at both global and domestic levels. Therefore, for a more exhaustive analysis, future research should factor in the probability and mean quantity of both under and oversupply in an emissions trading system.

The internal validity of the thesis is also weakened by not accounting for the emissions, apart from CO2, which also produces negative externalities that are mitigated by renewable energy sources. The inclusion of other emissions in the assessment could have positive or negative welfare effects at both the global and domestic levels, depending on which energy source is being replaced by FIT-induced energy production. For example, certain countries like France have a substantial dependence on nuclear energy, resulting in the production of other detrimental emissions that can be mitigated by a FIT. Moreover, most empirical research assumes that newly generated renewable energy replaces other polluting technologies, which may not always be the case according to York et al. (2019). Although assuming the applicability of FIT costs simplifies calculations, it can lead to significant bias when the assumption does not hold. While the risk of this happening may not be significant in some cases, I would argue it occurs more likely in countries with high levels of corruption and successful lobbying efforts. This is because dominant market players strive to maintain their profitability, and therefore, they are willing to take significant measures to protect their profitability.

All in all, the internal validity of the results decreases especially from the recent shift in market dynamics, carbon leakage, under or oversupply of allowances and the benchmark's failure to account for other emissions. Although there are some limitations in the internal validity of the findings, I think that they are fairly credible in suggesting that FITs have not been welfare-efficient policies due to their consistent cost difference in emissions offsetting across the continents. This suggests that the extensive historical use of the policy has resulted in significant welfare losses across the world. Therefore, its further use, especially in its historical magnitude, should be considered only if new research provides evidence of either decreased compensation costs or major findings of domestic externalities. However, countries with high marginal benefits from domestic FITs should be more interested in the policy and may want to invest in further analysis of the domestic externalities.

6 Conclusion

Feed-in tariffs (FITs) have proven to be a successful policy tool for incentivizing renewable energy production by offering predictable returns for investors. However, designing an optimal policy requires addressing country-specific issues to ensure that renewable energy is produced cost-effectively, increasing both global and domestic welfare compared to non-optimized FIT. Despite their widespread adoption, the current literature suggests that FITs may have led to global welfare losses by promoting the development of projects with higher offsetting costs than those available through emissions trading systems. Nevertheless, recent studies suggest that the domestic deployment of renewable energy produces net positive externalities that may compensate for the cost difference on rare occasions, which may result in net welfare benefits at the domestic level compared to an emissions trading system. However, current evidence suggests that the net positive domestic externalities of FITs would need to be, on average, significantly higher than the cost of comparable emissions allowances to be more welfare-efficient than an emissions trading system. Therefore, based on current evidence, most countries should avoid implementing the policy. Countries that wish to evaluate the welfare efficiency of the policy may want to identify the externalities that provide the most favorable benefit-to-cost ratio and model if they can prioritize these factors through the design of the FIT. Implementation of the policy may be justified if there is a significant net gain in domestic externalities.

Given the widespread use of FITs as a policy measure, incorrect implementation could lead to significant welfare losses on a global scale. However, there is no empirical research that comprehensively combines the domestic costs and benefits of FITs, which is crucial for deriving conclusive results on its domestic welfare implications. Therefore, to address this gap, further research should be conducted to examine the domestic externalities of FITs and compare the costs with alternative ways to offset emissions. Furthermore, it would be advantageous for future research to identify country-specific factors that may enhance or diminish the marginal benefits of domestic externalities. Insights gained from such research could inform policymakers worldwide about the appropriate circumstances for considering the use of FITs, thereby addressing the issue of weak generalizability of the empirical findings.

7 References

Abrell, J., Kosch, M., & Rausch, S. (2019). Carbon abatement with renewables: Evaluating wind and solar subsidies in Germany and Spain. Journal of Public Economics, 169, 172-202.

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. American Economic Review, 102(1), 131-166.

Alizamir, S., de Véricourt, F., & Sun, P. (2016). Efficient feed-in-tariff policies for renewable energy technologies. Operations Research, 64(1), 52-66.

Andini, C., Cabral, R., & Santos, J. E. (2019). The macroeconomic impact of renewable elect power generation projects. Renewable energy, 131, 1047-1059.

Ang, B. W., Choong, W. L., & Ng, T. S. (2015). Energy security: Definitions, dimensions and indexes. Renewable and Sustainable Energy Reviews, 42, 1077-1093.

Armstrong, A., Burton, R. R., Lee, S. E., Mobbs, S., Ostle, N., Smith, V., ... & Whitaker, J. (2016). Ground-level climate at a peatland wind farm in Scotland is affected by wind turbine operation. Environmental Research Letters, 11(4), 044024.

Babiker, M., Reilly, J., & Viguier, L. (2004). Is international emissions trading always beneficial?. The Energy Journal, 25(2).

Bakhtyar, B., Ibrahim, Y., Alghoul, M. A., Aziz, N., Fudholi, A., & Sopian, K. (2014). Estimating the CO2 abatement cost: Substitute Price of Avoiding CO2 Emission (SPAE) by Renewable Energy′ s Feed in Tariff in selected countries. Renewable and Sustainable Energy Reviews, 35, 205-210.

Bielecki, A., Ernst, S., Skrodzka, W., & Wojnicki, I. (2020). The externalities of energy production in the context of development of clean energy generation. Environmental Science and Pollution Research, 27, 11506-11530.

Böhringer, C., Cuntz, A., Harhoff, D., & Asane-Otoo, E. (2017). The impact of the German feed-in tariff scheme on innovation: Evidence based on patent filings in renewable energy technologies. Energy Economics, 67, 545-553.

Bollinger, B., & Gillingham, K. (2019). Learning-by-doing in solar photovoltaic installations. Available at SSRN 2342406.

Callaway, D. S., Fowlie, M., & McCormick, G. (2018). Location, location, location: The variable value of renewable energy and demand-side efficiency resources. Journal of the Association of Environmental and Resource Economists, 5(1), 39-75.

Couture, T., & Gagnon, Y. (2010). An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. Energy Policy, 38(2), 955-965.

Dijkgraaf, E., van Dorp, T. P., & Maasland, E. (2018). On the effectiveness of feed-in tariffs in the development of solar photovoltaics. The Energy Journal, 39(1).

Dong, C., Zhou, R., & Li, J. (2021). Rushing for subsidies: The impact of feed-in tariffs on solar photovoltaic capacity development in China. Applied Energy, 281, 116007.

Dröes, M. I., & Koster, H. R. (2016). Renewable energy and negative externalities: The effect of wind turbines on house prices. Journal of Urban Economics, 96, 121-141.

Feldman, S. (1982). Economic self-interest and political behavior. American Journal of Political Science, 446-466.

Gugler, K., Haxhimusa, A., & Liebensteiner, M. (2021). Effectiveness of climate policies: Carbon pricing vs. subsidizing renewables. Journal of Environmental Economics and Management, 106, 102405.

Höök, M., & Tang, X. (2013). Depletion of fossil fuels and anthropogenic climate change—A review. Energy Policy, 52, 797-809.

Joltreau, E., & Sommerfeld, K. (2019). Why does emissions trading under the EU Emissions Trading System (ETS) not affect firms' competitiveness? Empirical findings from the literature. Climate policy, 19(4), 453-471.

Klein, A., Held, A., Ragwitz, M., Resch, G., & Faber, T. (2008). Evaluation of different feed-in tariff design options: Best practice paper for the International Feed-in Cooperation. Energy Economics Group & Fraunhofer Institute Systems and Innovation Research, Germany, 28, 2019.

Lindman, Å., & Söderholm, P. (2016). Wind energy and green economy in Europe: measuring policy-induced innovation using patent data. Applied Energy, 179, 1351-1359.

Lipp, J. (2007). Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy Policy, 35(11), 5481-5495.

Ma, R., Cai, H., Ji, Q., & Zhai, P. (2021). The impact of feed-in tariff degression on R&D investment in renewable energy: The case of the solar PV industry. Energy Policy, 151, 112209.

Mah, D. N. Y., Cheung, D. M. W., Leung, M. K., Wang, M. Y., Wong, M. W. M., Lo, K., & Cheung, A. T. (2021). Policy mixes and the policy learning process of energy transitions: Insights from the feed-in tariff policy and urban community solar in Hong Kong. Energy Policy, 157, 112214.

Mattmann, M., Logar, I., & Brouwer, R. (2016). Hydropower externalities: A meta-analysis. Energy Economics, 57, 66-77.

Naegele, H., & Zaklan, A. (2019). Does the EU ETS cause carbon leakage in European manufacturing?. Journal of Environmental Economics and Management, 93, 125-147.

Ndiritu, S. W., & Engola, M. K. (2020). The effectiveness of feed-in-tariff policy in promoting power generation from renewable energy in Kenya. Renewable Energy, 161, 593-605.

Noailly, J., & Shestalova, V. (2017). Knowledge spillovers from renewable energy technologies: Lessons from patent citations. Environmental Innovation and Societal Transitions, 22, 1-14.

Nordhaus, W. D. (2017). Revisiting the social cost of carbon. Proceedings of the National Academy of Sciences, 114(7), 1518-1523.

Olabi, A. G., & Abdelkareem, M. A. (2022). Renewable energy and climate change. Renewable and Sustainable Energy Reviews, 158, 112111.

Qi, Y., Stern, N., Wu, T., Lu, J., & Green, F. (2016). China's post-coal growth. Nature

Geoscience, 9(8), 564-566.

Del Río, P., & Gual, M. A. (2007). An integrated assessment of the feed-in tariff system in Spain. Energy Policy, 35(2), 994-1012.

Reguant, M. (2019). The efficiency and sectoral distributional impacts of large-scale renewable energy policies. Journal of the Association of Environmental and Resource Economists, 6(S1), S129-S168.

Rosenthal, S. S., & Strange, W. C. (2008). The attenuation of human capital spillovers. Journal of Urban Economics, 64(2), 373-389.

Rubin, E. S., Azevedo, I. M., Jaramillo, P., & Yeh, S. (2015). A review of learning rates for electricity supply technologies. Energy Policy, 86, 198-218.

Schmidt, R. C., & Heitzig, J. (2014). Carbon leakage: Grandfathering as an incentive device to avert firm relocation. Journal of Environmental Economics and Management, 67(2), 209-223.

Taxation and Customs Union (2023). Carbon Border Adjustment Mechanism. https://taxation-customs.ec.europa.eu/green-taxation-0/carbon-border-adjustment-mechanism_en [Last accessed on 2023-04-12

York, R., & Bell, S. E. (2019). Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. Energy Research & Social Science, 51, 40-43.

Zerrahn, A. (2017). Wind power and externalities. Ecological Economics, 141, 245-260.