FCN | Future Energy Consumer Needs and Behavior

E.ON Energy Research Center

RWTH AACHEN UNIVERSITY

FCN Working Paper No. 9/2023

Tradable Performance Standards for a Greener Automobile Sector: An Economists' Appraisal of the German Greenhouse Gas Mitigation Quota

Constanze Liepold, Paul Fabianek and Reinhard Madlener

August 2023

Institute for Future Energy Consumer Needs and Behavior (FCN)

School of Business and Economics / E.ON ERC

FCN | Future Energy Consumer Needs and Behavior
E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

FCN Working Paper No. 9/2023

Tradable Performance Standards for a Greener Automobile Sector: An Economists' Appraisal of the German Greenhouse Gas Mitigation Quota

August 2023

Authors' addresses:

Constanze Liepold, Paul Fabianek, Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustraße 10
52074 Aachen, Germany
E-Mail: constanze.liepold@eonerc.rwth-aachen.de , paul.fabianek@eonerc.rwth-aachen.de,
RMadlener@eonerc.rwth-aachen.de

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 10, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Web: www.fcn.eonerc.rwth-aachen.de
E-mail: post_fcn@eonerc.rwth-aachen.de

Tradable Performance Standards for a Greener Automobile Sector: An Economists' Appraisal of the German Greenhouse Gas Mitigation Quota

Constanze Liepold[a] and Paul Fabianek[a] and Reinhard Madlener[a,b,*]

[a] *Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Mathieustrasse 10, 52074 Aachen, Germany*

[b] *Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU), Sentralbygg 1, Gløshaugen, 7491 Trondheim, Norway.*

August 2023

Abstract

The Greenhouse Gas (GHG) Mitigation Quota is a unique instrument in Europe that redistributes money from high-emission to low emission fuel markets, while forcing fuel distributors to reduce the average emissions of their fuels. This paper presents the design of the German 2022 GHG Quota, places it in the context of environmental policy instruments, and examines its impact on the affected fuel markets in relation to other environmental policy instruments. We aim to identify the strengths and weaknesses of the GHG Quota Trading as an alternative to allowance trading and carbon taxes, deliver results that can be applied in industry and policy making, and provide a basis for further research. Field research was conducted in the form of expert interviews. Furthermore, intermediaries and brokers were contacted via email and asked for transaction data. In addition, a qualitative literature review was conducted and publications of responsible authorities as well as relevant legal texts, were used to gather information. We find that the GHG Quota Trading overlaps with the instruments emission standards and emission trading scheme and therefore falls under the category of tradable performance standards. However, it also contains aspects of a subsidy and interacts directly or indirectly with several different markets.

Keywords: GHG Quota, environmental policy instrument, poolers

[*]Corresponding author. RMadlener@eonerc.rwth-aachen.de; Tel.+ 49 241 80 49820

1 Introduction

The transportation sector contributed a quarter of the global energy-related GHG emissions in 2019[1] (Jaramillo et al., 2022). Better engine and emission technology and blended fuels (such as E10) are *cet. par.* helping to reduce emissions. However, these measures are more than offset by increasing traffic volumes and the growing number and share of more powerful vehicles with comparatively high fuel consumption in private road transport. Government intervention is needed to reduce emissions to a socially, economically, and environmentally desirable level.

The "Fit for 55 Package" is the EU Commission's proposal to adapt existing legislation to the new, more ambitious climate policy targets and is also part of the “Green Deal” (European Council, 2022a). As a result, various regulations have been enacted for the road transportation sector to mitigate GHG emissions (Effort Sharing Decision 406/2009/EG, Effort Sharing Regulation (EU) 2018/842, Renewable Energy Directive (EU) 2018/2001 (RED II)). To protect the climate, the German government passed the Federal Climate Protection Act in 2019, which stipulates that GHG emissions from the transportation sector must be reduced to 85 Mt CO_{2eq} by 2030. GHG neutrality has to be reached in 2045 (KSG, 2019).

Germany's climate protection policy uses various instruments to achieve the targets set. In addition to the EU ETS, these include the National Emission Trading Scheme (NETS) for the transport and building sectors, subsidy measures, and the GHG Mitigation Quota, which is an extension of the former Biofuel Quota, which regulated a minimum share of biofuels in total fuel sales in Germany (BioKraftQuG, 2006).

The GHG Mitigation Quota legally obligates distributors of fossil fuels to reduce the average GHG emissions of the fuels they place on the market by a certain percentage. To meet this obligation, distributors must sell low emission fuels in addition to fossil ones, with high emissions. Hereafter referred to as fossil fuels. However, the legislation also allows other parties to be paid for replacing fossil fuels with low emission fuels. This scheme is known as GHG Quota Trading, not to be mixed up with ordinary GHG emission trading schemes with a cap such as the EU-ETS. Since 2022, owners of electric vehicles can be paid for replacing fossil fuels with electricity. This is the first-time private individuals have participated in GHG Quota Trading. This, together with a significantly increased GHG Quota level by 2030, has recently led to a renewed interest in GHG Quota Trading. In addition other countries besides Germany, such as Austria, are implementing instruments that are similar to the German GHG Quota

[1] The reference to 2019 emissions is because the Corona pandemic affected GHG emissions in 2020 and 2021 and is expected to return to pre-Corona levels from 2022 onwards (UBA, 2021).

Trading. Furthermore, the European Commission plans to introduce a standard similar to the GHG Quota into the regulatory framework with RED III (European Council, 2022b).

This paper aims shedding some light on the 2022 GHG Quota Trading system by providing a detailed overview of how the German 2022 GHG Quota Trading is structured and what kind of environmental policy instrument it is. In relation to other environmental policy instruments, its impact on the affected fuel markets is investigated.

Our paper is organized as follows. Section 2 and 3 give an overview of the related research as well as the methods used. Section 4 contains a characterization of the design of the GHG Quota Trading in the context of environmental policy instruments. Section 5 analyzes the markets for compliance option certificates. Section 7 discusses the policy effects, and section 6 concludes.

2 Related research

Our brief literature review reveals that there is still little published data on the German GHG Quota Trading, and that related literature is still scarce. Available studies typicallyfocus on the quota level and the low emission fuel mix. Fehrenbach and Jöhrens (2017) examine how the GHG Mitigation Quota could be developed into an ambitious instrument for climate protection in the transport sector. They postulate that it would be necessary to gradually increase the quota level in line with current climate protection goals, to include all potentially relevant low emission fuels, and to calculate the specific emissions of fuels over their entire life cycle. They also call for tradability of GHG mitigation certificates to ensure market transparency and liquidity. Meisel et al. (2020) evaluate the possible effects of the European and national climate protection goals on the German GHG Quota. They answer the question of how high the GHG Quota level should be in order to achieve 14% renewable energies share in the road transport sector and how high the quota level would have to be to meet the national climate protection targets. Naumann et al. (2021) predict the possible consequences of the GHG Quota and detail how these impacts fit into Germany's climate protection goals. Their study suggests that the quota level is too low for meeting the national climate protection targets. As the literature on this topic is still scarce, our study is the first to systematic and thoroughly examine the GHG quota as an environmental economic instrument and thus provides a basis for further research. Such research is necessary and usefull because the quota is the only environmental policy instrument in its form that directly redistributes money from the market for high-emission fuels to the market for low emission fuels, and it is becoming increasingly relevant as quota levels rise and the option of extending quota trading to other sectors is considered.

3 Data collection and method applied

The collection of information for the present study was mainly qualitative, as little has been published on GHG Quota Trading so far (Starr, 2014, p. 240). However, market data and emission series were also collected. Due to the exploratory nature of the work, no specific information needs could be identified. Accordingly, the data analysis was inductive.

Field research was conducted in the form of six expert interviews. These experts were all pooling firm members. Service provider work as an intermediaries between third parties distributing low emission fuels and quota obligated companies. In line with Madlener and Fabianek (2023) the interviews were semi-structured, as this allows unknown topics to be identified and discussed because not all questions are predetermined as is the case with structured interviews (Wilson, 2014). The structure of the interviews and a summary of the responses can be found in the Appendix (cf. Table A.1). The interviews were not transcribed as they are not at the core of our study. Furthermore, it has been shown that when research questions are relatively simple, this can substantially reduce the time required for data collection and analysis while still providing detailed and relevant information (Hill et al., 2022). Instead, the interviews were either recorded or protocolled and ex post verified by the interviewee. To collect market transaction data, 56 intermediaries were identified [December 2022] using the comparison portals autobild.de and verivox.de, and a Google search using the keywords „THG“ (GHG), “THG Quote“ (GHG Quota), “Treibhausgasminderungsquote“ (Greenhouse Gas Mitigation Quota), “THG Poolingunternehmen“ (GHG pooling firm) and “THG Zwischenhändler“ (GHG Intermediary). The identified intermediaries were then contacted via email and asked for transaction data. The level of detail in the request was not specified in order to obtain as many responses as possible. A total of eight firms provided data. In addition, eight brokers were contacted, of which one provided data. The intermediaries' data was used to validate the broker’s data. In addition to the field research, a qualitative literature review was conducted. The websites and publications of responsible authorities as well as relevant legal texts, were used to gather information.

4 Conceptional Design of the 2022 GHG Quota Trading Scheme

The GHG Quota applies to gasoline and diesel fuels (sect. 37a, para. 4a, cl. 1, BImSchG, 2022). By sect. 37a, para. 3, BImSchG, the GHG Quota shall be calculated according to eq. (1). The reference value *ref* contained in the equation expresses the amount of GHG would have been emitted if the total amount of fuel put into circulation by the firm subject to the quota had all been fossil (eq. (2)). For this purpose, the total amount of energy from gasoline Q_g, diesel fuel

Q_d and low emission fuels Q_i sold is multiplied by the average GHG emissions from the fossil fuel mix of 94.1 kg CO_{2eq} / GJ. This value is obtained by multiplying the fuel-specific GHG emissions of gasoline β_g (93.3 kg CO_{2eq} / GJ) and diesel β_d (95.1 kg CO_{2eq} / GJ) by the respective shares of the two fossil fuels in the total amount of energy from fossil fuels in Germany (sect. 3, 38th BImSchV, 2021).

$$quota = \frac{ref - \beta_d Q_d - \beta_g Q_g - \sum Q_i \beta_i}{ref} \quad (1)$$

$$ref = \left(Q_d + Q_g + \sum Q_i\right) 94.1 \ \frac{kg\ CO_{2eq}}{GJ} \quad (2)$$

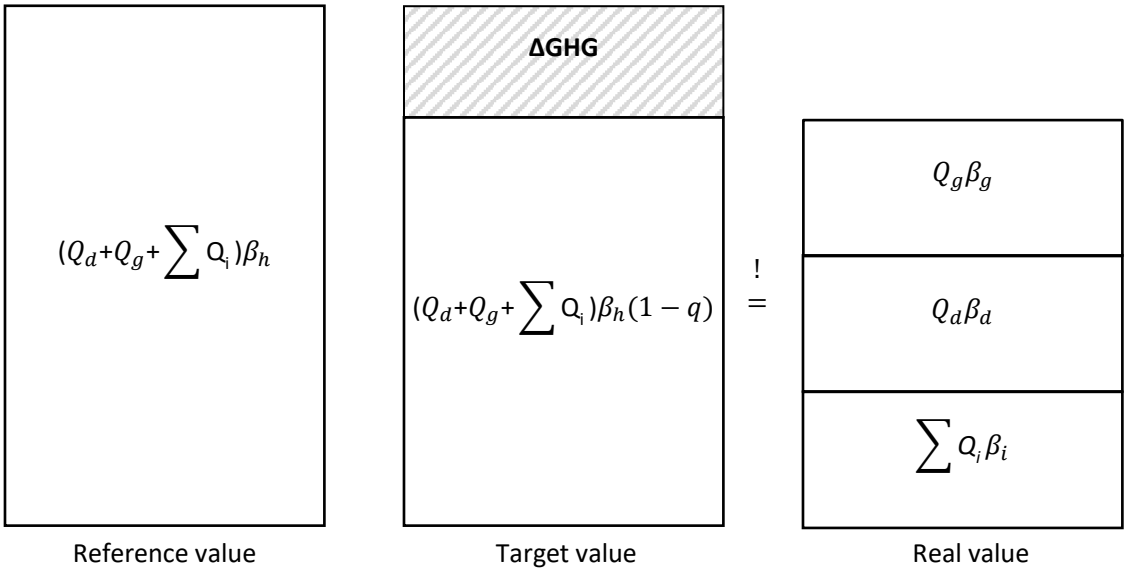

Figure 1: Illustration of the GHG Quota calculation

Several partly limited low emission fuels exist to meet the GHG Quota (sect. 37a, para. 5, BImSchG, October 19, 2022). Applicable compliance options are biofuels (fatty acid methyl ester, vegetable oil fuel, hydrogenated or hydrotreated vegetable oils), biogas, synthetic methane, liquefied petroleum gas, hydrogen, electric energy used in electric road vehicles and Upstream Emission Reductions (UER).

Low emission fossil fuels, such as compressed and liquefied natural gas (LNG) and liquefied petroleum gas (LPG), were also eligible as a compliance option until 2021. Biogenic fuels from food and feed crops, used cooking oils, and animal fats as well as palm oil are limited by sub-quotas (quotas within the GHG Quota).

Quota Trading allows obligated parties to fulfill their obligations by buying compliance option certificates from other parties. These certificates represent the placement of low emission fuels on the market on behalf of the obligated party, allowing them to credit the corresponding amount of energy against their quota (sect. 37a, para. 7, BImSchG, 2022). The trading can occur between two obligated firms or between an obligated party and a non-obligated party (sect. 37a, para. 6 and 7, BImSchG, 2022). Energy that has not yet contributed to the previous year's quota can be carried over to the following year (sect. 37a, para. 6, cl. 6 and para. 8, BImSchG, 2022). For electricity from renewable energy sources and the German electricity mix, the German Federal Environment Agency (UBA) provides specific GHG emission levels in kWh/kg CO_{2eq} as of the end of October of the previous year (sect. 5, para. 3, 4 and 20, 38th BImSchV, 2021). The German Biofuel Quota Office of the Customs *(Biokraftstoffquotenstelle)* is responsible for the nationwide monitoring of the GHG Quota.

Electricity used directly or indirectly in road transportation represents a special compliance option. Since low emission fossil fuels can only be used to meet the quota until 2021 (sect. 11, 38th BImSchV, 2021) and conventional biogenic fuels are limited in quantity (sect. 13, 38th BImSchV, 2021)[2], electricity has become increasingly important for meeting the quota. A distinction must be made between electricity used to produce compressed synthetic methane or hydrogen and charging electricity used to power battery electric vehicles. The energy quantities of hydrogen and P2X fuels can be included in the GHG Quota equation (eq. (1)) with a factor of two (sect. 14, para. 5, no. 1, 38th BImSchV, 2021). The energy quantity of charging electricity can be included in the equation with a factor of three (sect. 5, para. 2, no. 1, 38th BImSchV, 2021).

Since 2022, persons who can claim the corresponding amount of charging electricity and market it via quota trading are charging point operators or a representative on their behalf (sect. 5, 38th BImSchV, 2021). This means that end consumers can participate in trading for the first time and benefit directly from it. On the one hand, the electricity can come from publicly accessible charging stations, provided access to the charging station is possible for anyone at any time. On the other hand, the electricity used in electric vehicles may come from charging stations that are not accessible to the public. In this case, UBA certifies an average amount of

[2] Energy quantities exceeding the permissible sub-quota of 4.4% for biogenic fuels from feed and food crops and 1.9% for waste-based fuels are used to determine the GHG Quota with the base value of the fossil fuel mix (94.1 kg CO_{2eq}/GJ) (sect. 13, 38th BImSchV, 2021).

electricity of 2,000 kWh/year for each BEV after submission of the vehicle registration documents[3].

5 Market analysis

In this section, we provide an overview on the structure of the GHG emissions trading scheme and provide some market data.

5.1 Market structure

Figure 2 illustrates the Quota Trading mechanism. Q describes the energy content of the fuels, β the average specific emissions. Labels referring to fossil fuels with high emissions are indexed h, labels referring to fuels with low emissions are indexed l.

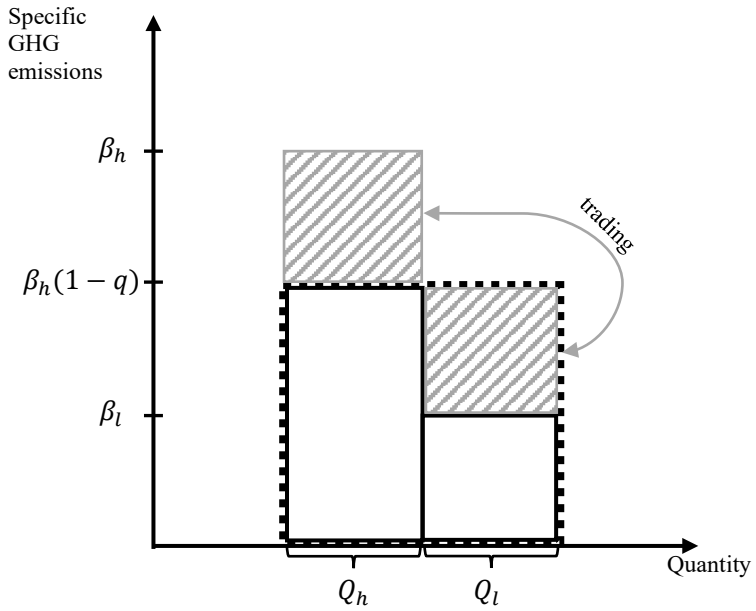

Figure 2: Illustration of the GHG Quota Trading

The GHG Quota Trading results from the quota q setting a target ($b_h(1-q)$) for average GHG emissions (see dotted square in Figure 2). Fossil fuels (the main products of quota-obligated parties) cause emissions above this target, while low emission fuels cause specific emissions below this target. Accordingly, lower emissions than allowed must be emitted elsewhere for each excess amount of emissions caused by fossil fuels to meet the average specific emissions target. If a firm's fossil fuel products cause excess emissions, it must purchase or generate a certain amount of GHG mitigation to meet its quota. GHG mitigation in this context is the mitigation of GHG emissions caused by the use of low emission fuels.

[3] The certified amount of electricity for light commercial vehicles is 3,000 kWh, and for electro buses 72,000 kWh (Breyer, 2021).

Although this is legally permitted, in practice, compliance option providers do not sell compliance option certificates themselves but instead through one or more brokers (e.g., STX, OLX, SCB, Marbridge, AFS, and OTC flow). These brokers collect offers and bids and establish contact between the quota obligator and the compliance option provider. The quota trading contract is concluded between the compliance option provider and the quota obligator.

The compliance option certificates are traded in euros per ton of emission mitigation. A distinction must be made between prices for compliance options with sub-quota and such without (no cap). The prices of the compliance option certificates fluctuate strongly over the course of a year. Figure 3 shows the bid and offer prices for no-cap certificates in 2022 based on data from a broker. It can be assumed that the actual transaction prices are between supply and demand. The average price, which is the average of bids and offers over the year, is 459 €/t CO_{2eq} (gray dotted line in Figure 3). The survey of sellers of compliance options from the no-cap sector showed that the actual transaction prices averaged 459 €/t CO_{2eq} over the year. Therefore, the assumption seems plausible. On the one hand, price fluctuations depend on demand for fossil fuels and the deadlines for submitting documents to prove compliance with the quota (price dip in week 15). On the other hand, prices depend on the number of compliance options placed on the market.

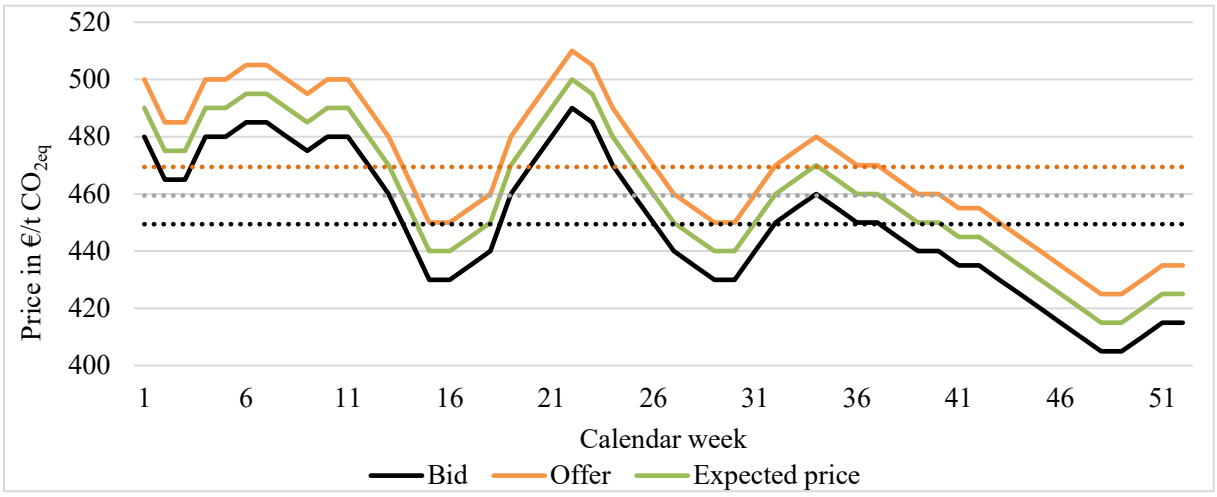

Figure 3: Bids, offers, and expected prices for no cap compliance option certificates in 2022

The prices for fuels with sub-quotas are lower than those for fuels without a cap because the ratio of demand to supply for compliance options without a cap is higher. Data series for compliance options with a sub-quota are unavailable because this market is too illiquid and trades do not occur every week. Generally, the discount for crop feedstock is about 20 €/t CO_{2eq},

and for non-crop[4] 10 €/t CO_{2eq} below the no-cap quotation. This difference can vary depending on supply and demand. UERs are also traded separately.

Before 2019, prices for certificates from unconventional compliance options were relatively stable between 150 €/t CO_{2eq} and 200 €/t CO_{2eq}. With an increase in the GHG Quota *q* from 4% to 7% in 2019, demand increased significantly, and quota prices reached up to 530 €/t CO_{2eq}. Between the fall of 2021 and the end of 2022, *compliance option certificate prices* were consistently above 400 €/t CO_{2eq}. Recently, they have fallen sharply and are now well below 400 €/t CO_{2eq} (eQuota, 2023). By 2030, the quota *q* will be raised to 25%, and at the same time, compliance options are expected to increase (Federal Government, 2022, p. 2). Therefore, substantial price uncertainty can be expected.

With the system change in the crediting of electricity for the operation of electric vehicles, the market has opened up for many partly private providers of fulfilment options, most of whom are not familiar with the quota trading system. For this reason, intermediaries, the so-called "poolers", became elementary, acting as service providers to sell the saved emissions from operators of public charging stations and the owners of electric vehicles to the obligated parties. In early November 2022, there was an adjusted number of about 60 pooling firms[5]. This number fluctuates a lot, especially since there are many pooling firms with speculative business models[6]. The market is expected to thin out in the future. There are many different types of *poolers*. These include firms that deal exclusively with the collection of GHG savings in the B2C sector, in the B2B sector, or both sectors, various firms whose core business is not GHG Quota Trading (such as electricity providers, insurers, car dealers, etc.), Non-Governmental Organizations, and the quota-obligated firms themselves. Further research is needed here to clarify the competitive environment in the market for *compliance option certificates* for charging electricity.

The *poolers* first obtain certification from UBA and then sell large bundles of *compliance option certificates* to the quota obligators, usually with the help of a broker. The operators of the charging stations or the owners of the electric vehicles receive a premium for the distribution of the charging electricity, which consists of the remuneration of the distributors of fossil fuels minus a margin for the brokers and the *poolers*.

[4] Biomass fraction of mixed municipal waste (Annex IX 8(b), RED II 2018/2001).
[5] Pooling providers with different names and identical imprints have been sorted out. The same applies to public utilities, insurance firms, etc. as they often cooperate with other pooling providers.
[6] Payment of sales proceeds to charging station operators before GHG mitigations are certified and resold.

5.2 Market data

The quota obligators sold their fossil fuels mostly via more than 14,000 public filling stations and about 350 motorway filling stations in Germany (BMWK, 2023)[7]. In addition to the major oil firms (Shell, BP/Aral, ExxonMobil (Esso), ConocoPhilips (Jet), and Total), there are numerous independent firms in the fuel market, most of which are organized in the form of federal associations (Bundesverband Mittelständischer Mineralölunternehmen e.V. and Bundesverband Freier Tankstellen). However, the large oil firms dominate the market with a market share of around 70% (German Federal Cartel Office, 2011).

In Germany, only fuels that meet the requirements of the German or European standard specified in the 10th BImSchV may be marketed. These include fuels with a biogenic content of 5 % to 85 % and so-called high-performance fuels without biogenic content (BMWK, 2023). The blending of biofuels enabled by far the highest GHG savings until 2021 and thus had the most significant impact on fulfilling the GHG Quota, as shown in Figure 5. The lower share of GHG mitigation from biofuel admixture in 2021 is due to the loss of the ability to carry forward emissions savings from the previous year to 2020. Therefore, savings from both 2019 and 2020 could be carried over to 2021[8]. As shown by the zoomed-in GHG emission mitigations in 2021 that were not achieved via admixture (right column in Figure 5), hydrogen and electricity, in particular, played almost no role in meeting the quota until 2021. However, they have been eligible since 2018. From 2022[9], the picture is likely to change because conventional biofuels are limited and the share of the mitigation coming from hydrogen, synthetic fuels, and electricity is increasing, as these fuels can be counted multiple times towards the quota by multiplying the fuel's energy content with a factor of two or three (sect. 14, para. 5, no. 1; sect. 5, para. 2, no. 1, 38th BImSchV, 2021).

[7] In addition to road transport, fossil fuels are also used in rail and (outbound) shipping, agriculture, construction and forestry, the tertiary sector, and domestic machinery and mobile equipment, and are not purchased at filling stations. This is also reflected in the differences between the fossil fuel emissions from diesel and gasoline of 189 Mt CO_{2eq} recorded by customs as part of the GHG quota control and the total emissions from road transport of 145 Mt CO_{2eq} in 2021, as reported by UBA (German Central Customs Authority, 2023; UBA, 2022).

[8] The federal government enacted this rule to carry over the overachievement from the 2019 commitment year to 2020 because it threatened to exceed the GHG mitigation and renewable energy targets for transportation set by EU regulations (sect. 3, para. 4, 2009/28/EG and sect. 7a, para. 2, 98/70/EG) (BMWK, 2018, p. 1).

[9] Data for 2022 will not be available until November 1, 2023. The data published then could form the basis for further research.

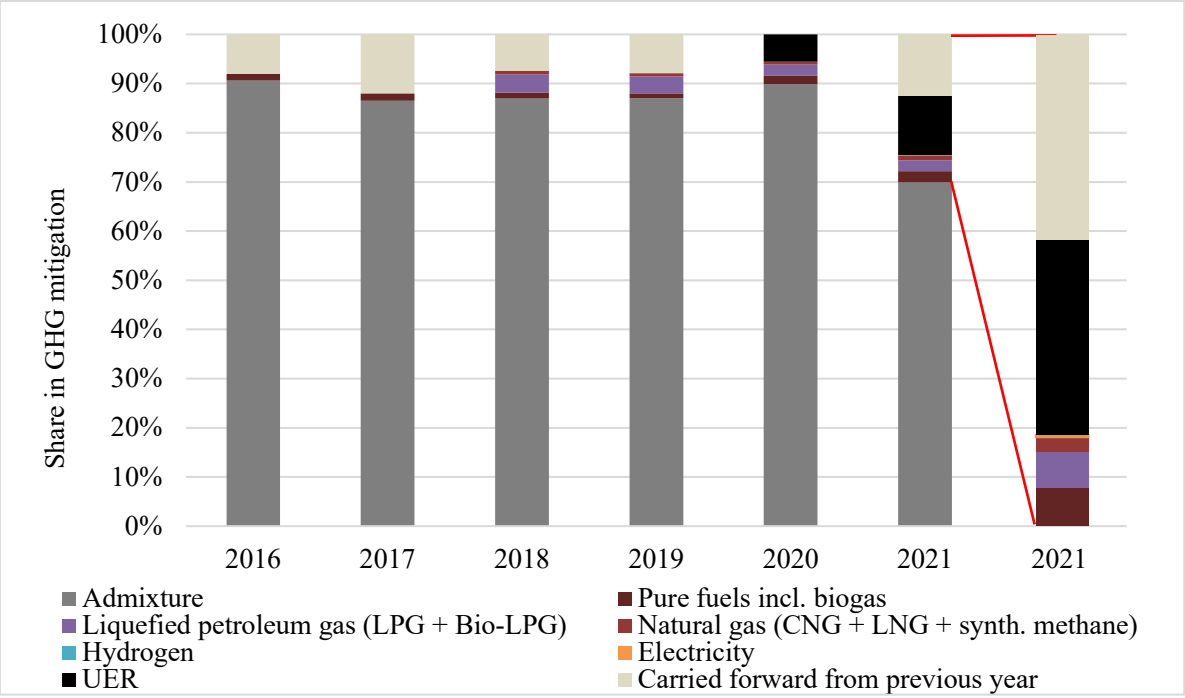

Figure 4: Share in GHG mitigation by energy source from 2015 to 2021, based on data from German Central Customs Authority (2023b)

Obligated parties aim to keep the cost of quota compliance as low as possible. This can be seen by considering the share of each compliance option in the GHG mitigation and the amount of energy used to achieve it. The share of energy used to meet the GHG Quota is shown in Figure 5. Although LPG has only a small GHG mitigation effect, in the years in which it is allowed (2018 to 2021), LPG is predominantly used to meet the quota compared to the other compliance options. This is probably because LPG is particularly cheap to market. Blending still makes the most significant contribution to GHG mitigation (see Figure 6) because the specific emissions of biofuels are significantly lower than those of LPG. From 2022 onwards, the GHG mitigation from the marketing of LPG will drop to zero, as low emission fossil fuels can no longer be used to meet the quota.

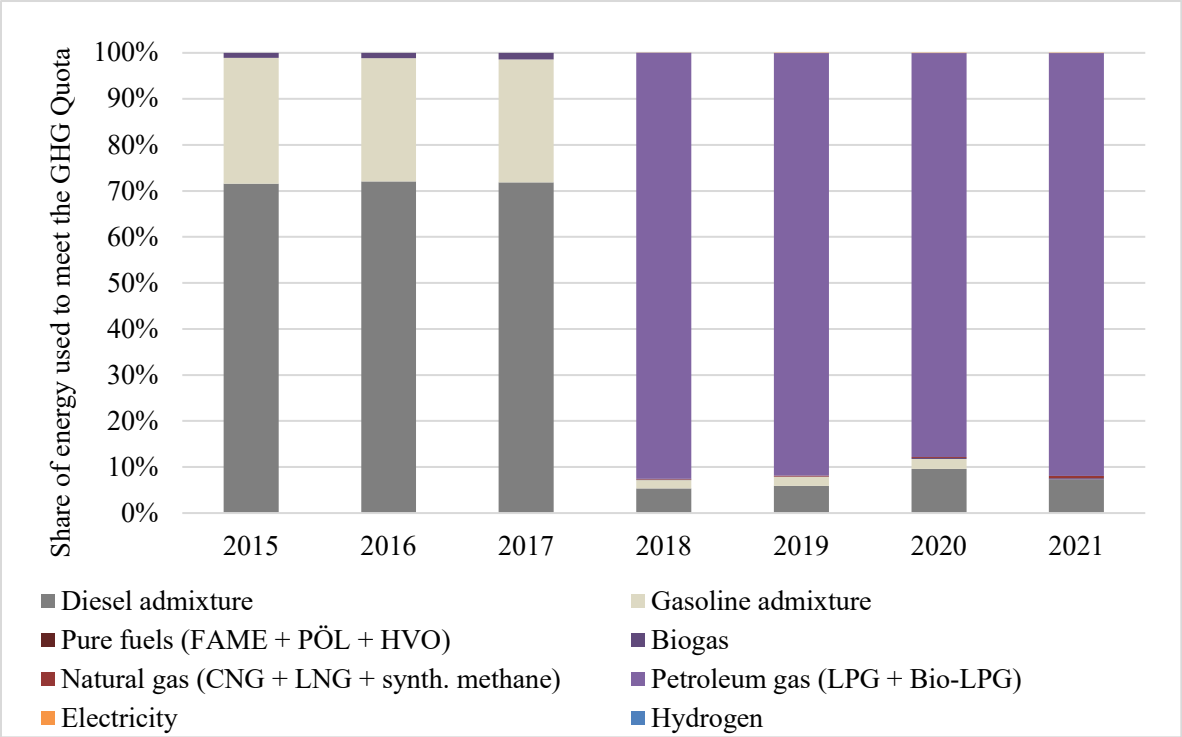

Figure 5: Share of energy used to meet the GHG Quota from 2015 to 2022, based on data from German Central Customs Authority (2023b)

In addition to the distributors of gasoline and diesel fuel, other market players are involved in GHG Quota Trading: the distributors of compliance options (who are partly identical to the quota-obligated parties) and the consumers of fuels. The motives of compliance option sellers cannot be described in general terms, as they depend on whether the quota-obligated parties market low emission fuels to comply with the quota or purchase *compliance option certificates*. If the former is the case, it is only important to sell the compliance options at the highest possible profit or the lowest possible loss. Quota obligators aim to avoid having to forego the sale of fossil fuels in order to meet the quota. Sellers of compliance options who are not subject to the quota also seek to maximize their profit, but their profit consists not only of the costs and proceeds from the sale of the compliance options but also from the sale of the *compliance option certificates*. Accordingly, high GHG Quota compliance costs are more advantageous to them.

Fuel consumers' motives are not purely economic, as evidenced by their stated preference for E5 over E10 fuels (BMWK, 2023). In addition to cost minimization, habits, personal attitudes, and other issues may play a role. This is an area for further research and is beyond the scope of this paper. However, the following subsection discusses the interactions between the different markets in more detail.

6 Multiple impact mechanisms

In this section, we start our analysis by comparing the GHG Quota Trading towards other environmental economics instrument and then show its effects on the affected markets and on the impact of other environmental policy instruments.

6.1 GHG quota trading in the context of environmental policy instruments

The GHG Quota Trading is a hybrid instrument that has characteristics of both regulatory and market-oriented instruments. On the one hand, GHG Quota Trading resembles regulatory instruments, particularly the command and control instrument described in subsection 2.3. The similarity lies in the fact that legislation sets a specific requirement—the GHG Quota—which each firm must meet. The GHG Quota Trading overlaps with both technology mandates and performance standards within the subcategories of command and control instruments. The legislation restricts the applicable technologies, in some cases through a sub-quota, which is the common feature of the GHG Quota Trading and technology mandates. However, various compliance options are allowed, and the GHG Quota sets an emission limit comparable to a performance standard. On the other hand, the GHG Quota Trading has characteristics of market-oriented instruments, as trading in *compliance option certificates* is legally permitted. In this respect, trading is similar to trading in allowance certificates, but the number of environmental allowances is not fixed. The GHG Quota Trading resembles the internalization strategy referred to as tradable performance standards, which combines regulatory and market-oriented instruments (Pizer, 1999, p. 9; Yeh et al., 2021, p. 1).

Unlike trading in Green Certificates and Guarantees of Origin, which are based on the origin of the energy (Wimmers and Madlener, 2020, p. 3), trading in GHG quotas is based on exceeding a standard. Tradable performance standards mandate a standard that cannot be achieved with conventional technology (Lee et al., 2010) or that imposes higher costs (Gerard and Lave, 2005). Products with a performance above this standard earn credits they can sell; products with a performance below the standard must acquire those credits to comply with the standard (Burtraw et al., 2012).

Tradable performance standards are widely used in the U.S. electricity and transportation sectors (Yeh et al., 2021, pp. 1–2). Exemplary are the Renewable Portfolio Standards (RPS) implemented in 29 states to improve the U.S. electricity market's environmental friendliness. These standards require utilities to provide a minimum amount of electricity from certain renewable energy sources (EIA, 2022; Goulder et al., 2022, p. 2). Another example of tradable performance standards are white certificates, also referred to as Energy Savings Certificates or

Energy Efficiency Credits, which certify energy savings that can either be used to meet one's own legally mandated energy savings targets or sold to other obligated market participants. Such certificates are traded in Italy and Poland, for example (Rosenow et al., 2020). Similar policies in the U.S. transportation sector include GHG rates for cars and trucks, zero-emission vehicle programs, the National Renewable Fuel Standard, and California's Low Carbon Fuel Standard (Yeh et al., 2021, p. 2).

The world's largest carbon emissions trading system, launched in China in 2021, is a performance-based, standards-based form of emissions trading, too (Goulder et al., 2022, p. 1; Yeh et al., 2021, p. 1). A maximum amount of GHGs is allowed per MWh. Each MWh that a power plant produces receives the number of allowances equal to the limit free of charge. Power plants that emit fewer GHGs can sell some of their allowances, whereas those that emit more GHGs must buy additional allowances (Jin et al., 2020, p. 2).

Despite the high degree of similarity with other internalization strategies already implemented, the GHG Quota Trading Scheme has some specific features that make it difficult to compare its efficiency with different internalization strategies. Firstly, and in contrast to the U.S. national renewable fuel standard or the former German Biofuel Quota, the GHG Quota is not a quota that prescribes the proportional use of a certain energy or technology, but, as the name suggests, the mitigation of GHGs. Thus the GHG Quota aims for technological neutrality. However, this neutrality is limited by the lump-sum determination of the specific GHG emissions, multiple crediting of certain compliance options, and the quantitative restriction or requirement of certain compliance options.

Secondly, in contrast to quota-based tradable green certificate schemes, the quota does not affect the entire fuel market, but only the distributors of fossil diesel fuel and gasoline. Related to this is that fuel is not a homogeneous product like electricity. The fuel market is heterogeneous because different fuel types cannot be substituted at will. As a result, the GHG Quota Trading directly impacts two markets that influence each other and interacts with the markets for all compliance options. The effect of this characteristic is discussed in more detail hereafter. The markets affected by the quota, and those affecting the quota are shown in Figure 6.

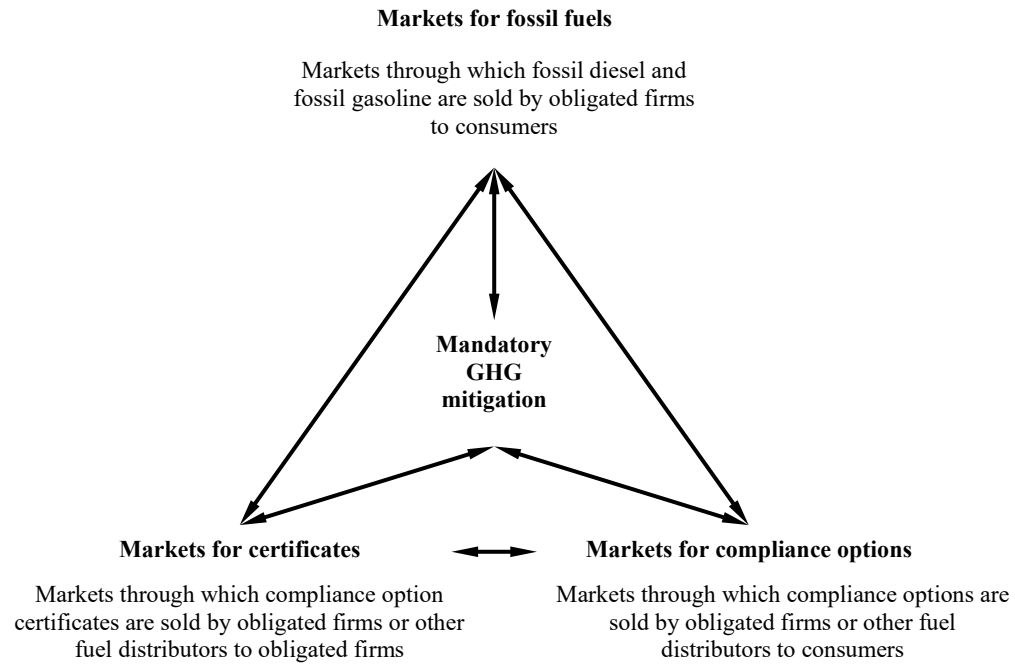

Figure 6: The markets affected by the GHG Quota and the markets affecting the GHG Quota

Finally, it should be emphasized that the quota cannot only be met by obligated parties selling low emission fuels themselves and by other quota-obligated parties selling them. Instead, non-quota-obligated parties can also sell certificates to the quota-obligated parties, which certify the sale of their energy quantity with corresponding GHG emissions. In this way, compliance is partially achieved outside the quota-obligated firms and traded in a broader market to which both quota-obligated firms and many other actors have access. As a result, the costs incurred by the GHG Quota Trading Scheme are not redistributed exclusively among quota-obligated parties or incurred through government levies, as is the case with the classic tax and certificate trading solutions. Some of the costs are caused by the trading of certificates, through which payments are made to distributors of low emission fuels, resulting in cost reductions for them that are passed on to end users through the relevant fuel market, thereby increasing the demand for lower-emission fuels.

6.2 Interactions of the affected markets

An analysis of the interactions of all the markets involved, as well as the influence of and on the quota, is beyond the scope of this study but deserves further research. However, some examples of interactions are described in order to demonstrate the complexity of the GHG Quota scheme.

Figure 7 shows a schematic illustration of the supply and demand curves for the gasoline and compliance option certificate markets.

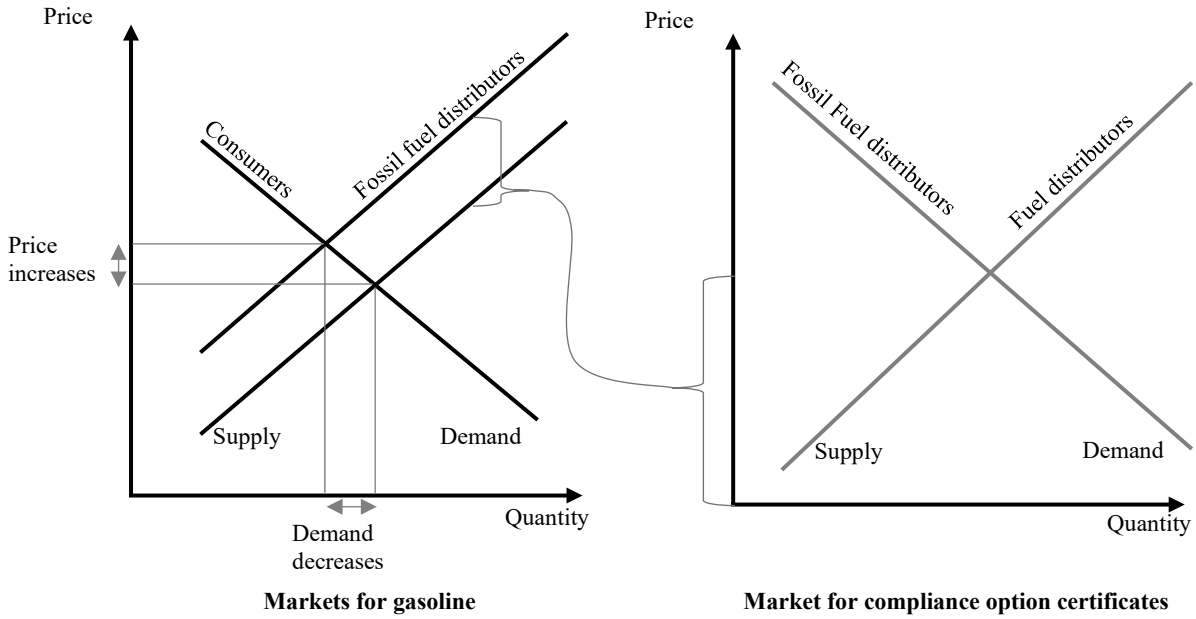

Figure 7: Schematic representation of the gasoline market and the compliance option certificate market

The demand for gasoline results from the intersection of the marginal utility and supply functions. The GHG Quota imposes costs on gasoline sellers. These costs increase the price of gasoline by Δp. As a result, the demand for gasoline decreases, albeit slightly, because the demand for fuel is relatively inelastic (Dahl, 2012, p. 4). As the demand for gasoline decreases, the absolute amount of GHG emissions and energy required by the obligated parties decreases, and the demand for *compliance option certificates* also decreases. This decrease in demand, in turn, causes the price of *compliance option certificates* to decrease (also shown in Figure 7). Thus, the cost caused by the quota decreases, which ultimately causes the price of gasoline to decrease. This decrease, in turn, increases the demand for gasoline, which increases the absolute number of certificates needed. Figure 8 summarizes these effects. Although the price increase is unlikely to be equal to the price drop (price symmetry), and the market price (in the absence of exogenous influences) would asymptotically approach a fixed price, it should be noted that the price of gasoline fluctuates on its own, even with an unchanged GHG Quota and constant exogenous influences.

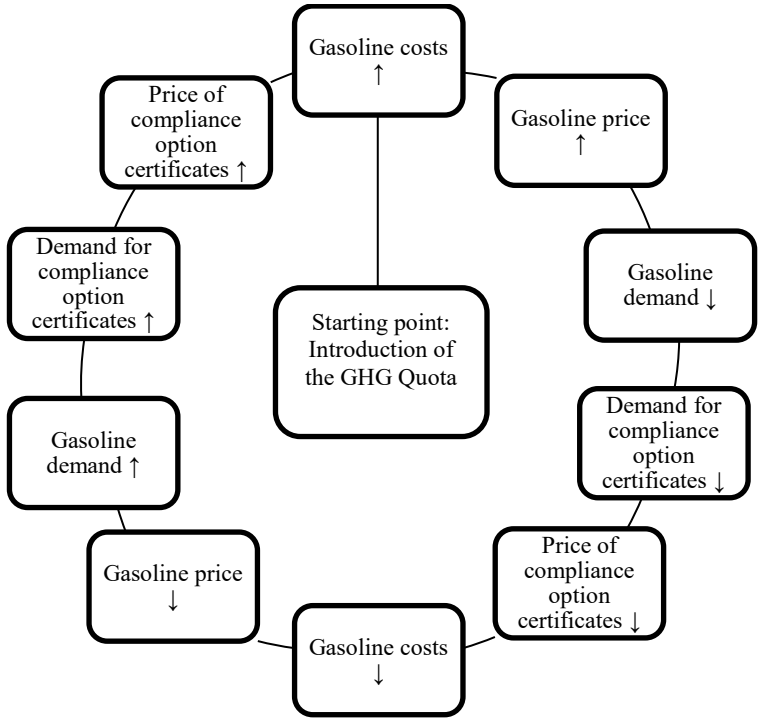

Figure 8: Price fluctuations as a result of the introduction of the GHG Quota

As noted above, firms subject to the quota can reduce their share of fossil fuel by selling compliance options or buying certified energy and GHG mitigations. In the first case, the firms face costs caused by lost profits. In the second case, they incur costs for procurement or production of compliance options but also profit by selling them. They will only buy certified energy from other parties if it is neither economically efficient for them to produce all the energy, they need from compliance options nor reduce their fossil fuel sales. Thus, on the one hand, the demand for the *compliance option certificates* depends on the profit from the sale of fossil fuels, which in turn depends on the market prices for fossil fuels, which in turn are influenced by the quota and the financial burden it places on the quota obligators. On the other hand, the demand for *compliance option certificates* depends on the price of the respective compliance options. This price results from the market equilibrium derived from the demand curve for each compliance option and the marginal cost of that compliance option's production. The demand curve is influenced by, among other factors, the prices of fossil fuels specifically, the prices for diesel and gasoline rise (e.g., due to the quota), consumers may be inclined to switch to vehicles with alternative drive systems. This effect will increase in the future as technological progress, and infrastructure development reduce the competitive disadvantages of vehicles that run on compliance options (Burchardt et al., 2021, p. 18; Gebert et al., 2018, p. 178; Pfluger et al., 2017, pp. 83–90). The ability to pay suppliers of compliance options for the

sale of these options has another effect. The proceeds from the sale reduce the cost of the compliance options. This also lowers the market equilibrium price on the markets for compliance options, which in turn increases the loss that the quota-obligated firms incur by putting the compliance options on the market themselves. These relationships are illustrated in Figure 9. As a result, quota obligators may be more inclined to purchase the *compliance option certificates*, which in turn affects the market equilibrium price of these certificates, and thus the market equilibrium price of fossil fuels, further fueling the process described above and shown in Figure 9.

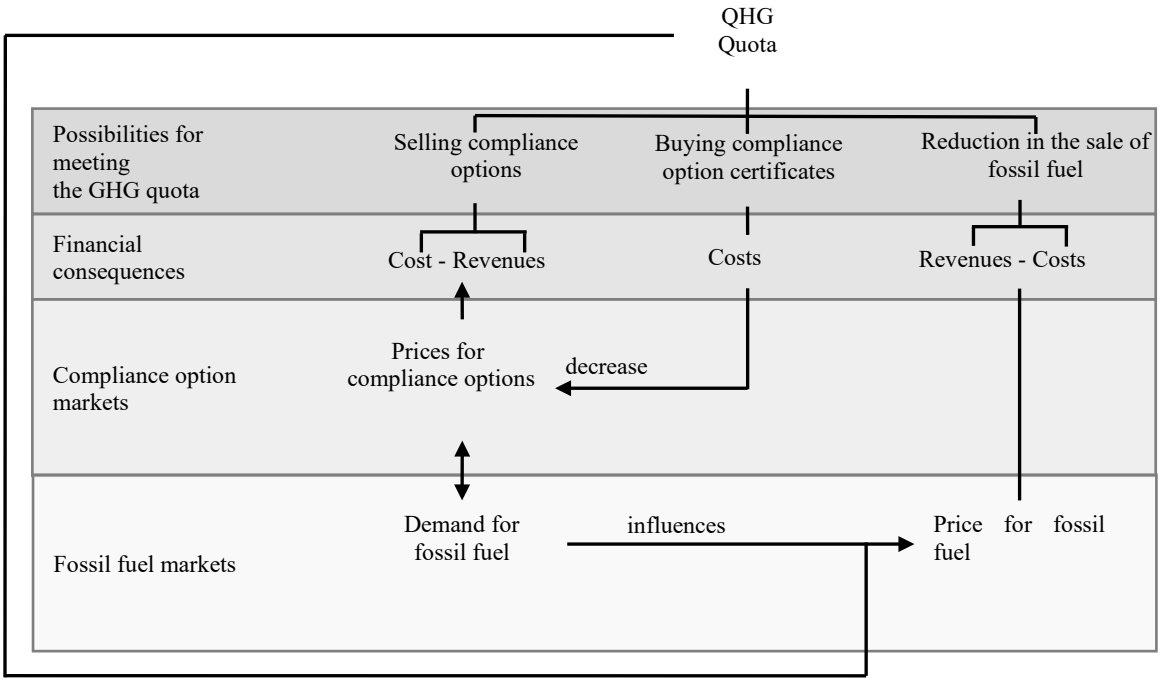

Figure 9: Interactions due to different ways of meeting the GHG Quota

None of the markets (compliance option markets, fossil fuel markets, or *compliance option certificate* market) can be examined in isolation due to the interrelatedness. Therefore, all markets must be considered jointly in an economic analysis.

The interaction of the different markets affected by the quota is complicated because, in addition to the GHG Quota Trading, other environmental policy instruments have been introduced in Germany to internalize the external effects of transportation. These environmental policies and the GHG Quota Trading have interactive effects. Within the policy package, a particular focus is on policies to promote electric cars. These instruments and the GHG Quota influence the market for *compliance option certificates*, which certifies electric energy used in electric road vehicles.

Due to its design, owners of electric vehicles can benefit from the GHG Quota Trading. The compensation from the sale of the *compliance option certificate* corresponding to the vehicle is, like the Environmental Bonus, a subsidy that makes purchasing purely electric car more attractive. The Environmental Bonus is a grant of €6,750 (€4,500 government share + €2,250 manufacturer share) that vehicle owners receive once they register a new electric car (BMWK, 2022). However, while the environmental bonus decreases digressively from 2023, the premium from the sale of the certificates could increase in the coming years as the share of renewables in the German electricity mix increases (Liepold et al. 2023). Proceeds from the sale of the *compliance option certificates* may help mitigate a possible decline in demand for electric vehicles caused by the reduction in the Environmental Bonus.

The EU Council and Parliament decided that zero fleet limits will apply to newly registered passenger cars from 2035 onwards (EP, 2022). A zero fleet limit value means no more GHG emissions may be caused by driving with all newly registered passenger cars in the EU. Therefore, all newly registered cars will no longer be allowed to burn fossil diesel or gasoline. Fleet limits consequently dramatically reduce the demand for fossil fuels and increase the supply of *compliance option certificates*, resulting in meager prices for *compliance option certificates* that significantly reduce the incentive to substitute fossil fuels with low emission fuels (Liepold et al. 2023).

The National Emissions Trading Scheme (NETS) puts a price on GHG emissions from transport and heat generation. In the first phase, this will be a fixed levy ranging from 25 €/t CO_{2eq} in 2021 to 45 €/t CO_{2eq} in 2025[10]. In 2026, there will be a switch to certificate trading, in which a limited volume of emission allowances will be auctioned within a price corridor of 55 €/t CO_{2eq} to 65 €/t CO_{2eq} (BEHG, 11.09.22). The German government excludes hydrogen and fuels of biogenic origin that meet the sustainability criteria of the *Biofuel Sustainability Ordinance* from GHG pricing. E-fuels are treated the same way as fossil fuels, and distributors of these fuels are required to purchase allowances. The charged parties are, therefore, partly identical to the quota-obligated parties.

Although the German Energy Tax has to be paid for each liter of fuel, it has a similar effect as the financial burden resulting from the NETS. The tax is also levied on sellers of fossil and synthetic fuels unless the fuels meet the criteria for biofuels or are associated with emission-free use (EnergieStG, September 19, 2022). The financial burden of the energy tax, converted to the emissions of one liter of fuel, ranges from 58 €/t CO_{2eq} to 64 €/t CO_{2eq}. GHG pricing and

[10] Formally, emission allowances are purchased. However, the quantity of these emission allowances is not limited, which means that it is a price control and not a quantity control instrument (Puls and Schaefer, 2020).

the price change resulting from GHG Quota Trading have different effects on consumer prices. While GHG taxes create a greater incentive to avoid fuels in general (Liepold et al. 2023), GHG Quota Trading creates an incentive to avoid fossil fuels without imposing the exact cost on consumers (Yeh et al., 2021). By combining the two instruments, the burden on consumers and the associated reduction in demand can be controlled. The combination of GHG Quota Trading and a classic allowance trading system results in lower obligations for fossil fuels under the allowance trading system (Yeh et al., 2021, p. 11). These reduced obligations diminish the abatement effect of the allowance trading as the price of allowances falls (Abrell, 2011; Fischer, 2011; Nelson et al., 2015; Tsao et al., 2011).

7 Conclusion and outlook

The GHG Quota Trading overlaps with the standard scheme and allowance trading and therefore falls under the category of tradable performance standards. However, it also contains aspects of a subsidy. Although the system is similar to other environmental policy instruments, such as the Green Electricity Certificate Trading or the California Fuel Standard, it has certain characteristics that make it challenging to evaluate and compare with other instruments. These characteristics include that the quota interacts directly or indirectly with several different markets.

Two limitations must also be acknowledged with respect to the research method. Due to the small sample size of interviewees, caution must be applied regarding the prices of *compliance option certificates*, as the results may not be generalizable to all markets. In addition, the expert interviewees were all pooling firm members, which may have made the responses subjective and, therefore, susceptible to bias.

Given the complexity of the topic, this study can only provide an overview and offer some ideas for further research. What needs to be clarified now are the competitive conditions in the market for *compliance option certificates* and the influence of fuel consumption patterns on the impact of the GHG Quota. It would also be interesting to closer look at the market for *compliance option certificates* for charging electricity.

References

Abrell, J., 2011. Private Transport and the European Emission Trading System: Revenue Recycling, Public Transport Subsidies, and Congestion Effects. In *SSRN Journal*. DOI: 10.2139/ssrn.1844300.

BMWK, 2023. Markets for motor and other fuels. -Federal Ministry for Economics Affairs and Climate. Available online at https://www.bmwk.de/Redaktion/EN/Artikel/Energy/petroleum-markets-for-

motor-and-other-fuels.html, checked on 2/28/23.

BMWK - German Federal Ministry for Economic Affairs and Climate Action, 2022. Bekanntmachung der Richtlinie zur Förderung des Absatzes von elektrisch betriebenen Fahrzeugen (Umweltbonus). Available online at https://www.bmwk.de/Redaktion/DE/Downloads/B/bekanntmachung-der-richtlinie-zur-foerderung-absatzes-von-elektrisch-betriebenen-fahrzeugen-umweltbonus.pdf?__blob=publicationFile&v=6, checked on 3/12/23.

BMWK - German Federal Ministry for Economic Affairs and Climate Action, 2018. Referentenentwurf des Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit Erste Verordnung zur Änderung der Verordnung zur Festlegung weiterer Bestimmungen zur Treibhausgasminderung bei Kraftstoffen. Available online at https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Glaeserne_Gesetze/19._Lp/38_bimschv/entwurf/38_bimschv_refe_bf.pdf, checked on 2/28/23.

Breyer, A., 2021. Bekanntmachung des Schätzwertes der anrechenbaren energetischen Menge elektrischen Stroms für ein reines Batterieelektrofahrzeug gemäß § 7 Absatz 3 der Verordnung zur Festlegung weiterer Bestimmungen zur Treibhausgasminderung bei Kraftstoffen. Available online at https://www.umweltbundesamt.de/sites/default/files/medien/366/dokumente/banz_at_16.12.2021_b3.pdf, checked on 3/12/23.

Burchardt, J., Franke, K., Herhold, P., Honhaus, M., Humpert, H., Päivärinta, J., Richenhagen, E., Ritter, D., Schönberger, S., Schröder, J., Strobl, S., Tries, C., Türpitz, A., 2021. Climae Paths 2.0 A Program for Climate and Germany's Future Development. BCG. Available online at https://www.bcg.com/climate-paths, checked on 2/13/23.

Burtraw, D., Fraas, A.G., Richardson, N., 2012. Tradable Standards for Clean Air Act Carbon Policy. Resources for the Future. Available online at https://www.rff.org/publications/working-papers/tradable-standards-for-clean-air-act-carbon-policy/, checked on 3/13/23.

Dahl, C.A., 2012. Measuring global gasoline and diesel price and income elasticities. In *Energy Policy* 41, 2–13. DOI: 10.1016/j.enpol.2010.11.055.

EIA - U.S. Energy Information Administration, 2022. Renewable energy explained - portfolio standards. Available online at https://www.eia.gov/energyexplained/renewable-sources/portfolio-standards.php, checked on 2/1/23.

EP - European Parliament, 2022. Deal confirms zero-emissions target for new cars and vans in 2035. Available online at https://www.europarl.europa.eu/news/en/press-room/20221024IPR45734/deal-confirms-zero-emissions-target-for-new-cars-and-vans-in-2035, checked on 2/9/23.

eQuota, 2023. THG-Quoten: Aktuelle Preise, Quotenerlöse und Entwicklungen. Available online at https://equota.de/quotenerloese/, checked on 3/3/23.

European Council, 2022a. European Green Deal. Available online at https://www.consilium.europa.eu/en/policies/green-deal/, checked on 3/9/23.

European Council, 2022b. "Fit for 55": Council agrees on higher targets for renewables and energy

efficiency. Available online at https://www.consilium.europa.eu/en/press/press-releases/2022/06/27/fit-for-55-council-agrees-on-higher-targets-for-renewables-and-energy-efficiency/, checked on 2/13/23.

Fabianek, P.; Madlener, R. (2023b): Multi-Criteria assessment of the user experience at E-Vehicle charging stations in Germany. In Transportation Research Part D: Transport and Environment 121. DOI: 10.1016/j.trd.2023.103782.

Federal Government, 2022. Entwurf eines Gesetzes zur Weiterentwicklung der Treibhausgasminderungs-Quote. Available online at https://dserver.bundestag.de/btd/19/274/1927435.pdf, checked on 2/13/23.

Fehrenbach, H., Jöhrens, J., 2017. Weiterentwicklung der THG-Quote als Instrument des Klimaschutzes. ifeu – Institut für Energie- und Umweltforschung Heidelberg. Available online at https://www.baden-wuerttemberg.de/fileadmin/redaktion/m-mvi/intern/Dateien/PDF/20180104_IFEU_Kurzstudie_THG-Einsparquote_als_Instrument_für_Klimaschutz.pdf, checked on 3.9.23.

Fischer, C., 2011. Market power and output-based refunding of environmental policy revenues. In *Resource and Energy Economics* 33(1), 212–230. DOI: 10.1016/j.reseneeco.2010.04.011.

Gebert, P., Herhold, P., Burchardt, J., Schönberger, S., Rechenmacher, F., Kirchner, A., Kemmpler, A., Wünsch, M., 2018. Climate Paths for Germany. BCG. Available online at https://www.bcg.com/publications/2018/climate-paths-for-germany-english, checked on 2/13/23.

Gerard, D., Lave, L.B., 2005. Implementing technology-forcing policies: The 1970 Clean Air Act Amendments and the introduction of advanced automotive emissions controls in the United States. In *Technological Forecasting and Social Change* 72, 761–778. DOI: 10.1016/j.techfore.2004.08.003.

German Central Customs Authority, 2023. Zoll online - Statistiken. Available online at https://www.zoll.de/DE/Fachthemen/Steuern/Verbrauchsteuern/Treibhausgasquote-THG-Quote/Statistiken/statistiken_node.html, checked on 2/28/23.

German Federal Cartel Office, 2011. Sektoruntersuchung Kraftstoffe - Abschlussbericht. Available online at https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Sektoruntersuchungen/Sektoruntersuchung%20Kraftstoffe%20-%20Abschlussbericht.pdf?__blob=publicationFile&v=5, checked on 3/12/23.

Goulder, L.H., Long, X., Lu, J., Morgenstern, R.D., 2022. China's unconventional nationwide CO2 emissions trading system: Cost-effectiveness and distributional impacts. In *Journal of Environmental Economics and Management* 111. DOI: 10.1016/j.jeem.2021.102561.

Hill, Z., Tawiah-Agyemang, C., Kirkwood, B., Kendall, C., 2022. Are verbatim transcripts necessary in applied qualitative research: experiences from two community-based intervention trials in Ghana. In *Emerging Themes in Epidemiology* 19. DOI: 10.1186/s12982-022-00115-w.

Jaramillo, P., Kahn Ribeiro, S., Newman, P., Dhar, S., Diemuodeke, O.E., Kajino, T., Lee, D.S.,

Nugroho, S.B., Ou, X., Hammer Strømman, A., Whitehead, J., 2022. Transport. IPCC - Intergovernmental Panel on Climate Change. Available online at https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf, checked on 3/12/23.

Jin, Y., Liu, X., Chen, X., Dai, H., 2020. Allowance allocation matters in China's carbon emissions trading system. In *Energy Economics* 92. DOI: 10.1016/j.eneco.2020.105012.

Liepold, C., Fabianek, P., Madlener, R. (2023): A Critical Evaluation of the 2022 Greenhouse Gas Mitigation Quota in Germany from an Environmental Economics and Policy Perspective, FCN Working Paper No. 10/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Lee, J., Veloso, F.M., Hounshell, D.A., Rubin, E.S., 2010. Forcing technological change: A case of automobile emissions control technology development in the US. In *Technovation* 30, 249–264. DOI: 10.1016/j.technovation.2009.12.003.

Meisel, K., Millinger, M., Naumann, K., Müller-Langer, F., Majer, S., Thrän, D., 2020. Future Renewable Fuel Mixes in Transport in Germany under RED II and Climate Protection Targets. In *Energies* 13(7), 1712. DOI: 10.3390/en13071712.

Naumann, K., Müller-Langer, F., Meisel, K., Majer, S., Schröder, J., Schmieder, U., 2021. Further development of the German greenhouse gas reduction quota, Background paper. Deutsches Biomasseforschungszentrum. Available online at https://www.dbfz.de/fileadmin/user_upload/Referenzen/Statements/Background_Paper_GHG_Quota.pdf, checked on 3/12/23.

Nelson, T., Reid, C., McNeill, J., 2015. Energy-only markets and renewable energy targets: Complementary policy or policy collision? In *Economic Analysis and Policy* 46, 25–42. DOI: 10.1016/j.eap.2015.04.001.

Pfluger, B., Tersteegen, B., Franke, B., 2017. Langfristszenarien für die Transformation des Energiesystems in Deutschland. Frauenhofer isi, consentec GmbH, ifeu. Available online at https://www.bmwk.de/Redaktion/DE/Downloads/B/berichtsmodul-0-zentrale-ergebnisse-und-schlussfolgerungen.pdf?__blob=publicationFile&v=6, checked on 2/13/23.

Pizer, W.A., 1999. Choosing Price or Quantity Controls for Greenhouse Gases. *Climate Issues Brief* 17.

Puls, T., Schaefer, T., 2020. Nationaler Emissionshandel für Verkehr und Wärme. Puls Gutachten. Available online at https://www.iwkoeln.de/studien/thomas-puls-thilo-schaefer-nationaler-emissionshandel-fuer-verkehr-und-waerme.html, checked on 2/9/23.

Rosenow, J., Skoczkowski, T., Thomas, S., Węglarz, A., Stańczyk, W., Jędra, M., 2020. Evaluating the Polish White Certificate scheme. In *Energy Policy* 144, 111689. DOI: 10.1016/j.enpol.2020.111689.

Starr, M.A., 2014. Qualitative and Mixed-Methods Research in Economics: Surprising Growth, Promising Future. In *Journal of Economic Surveys* 28, 238–264. DOI: 10.1111/joes.12004.

Tsao, C.-C., Campbell, J.E., Chen, Y., 2011. When renewable portfolio standards meet cap-and-trade regulations in the electricity sector: Market interactions, profits implications, and policy redundancy.

In *Energy Policy, Special Section: Renewable energy policy and development* 39, 3966–3974. DOI: 10.1016/j.enpol.2011.01.030.

UBA, 2022. Greenhouse gas emissions rose by 4.5 percent in 2021. Available online at https://www.umweltbundesamt.de/en/press/pressinformation/greenhouse-gas-emissions-rose-45-percent-in-2021, checked o 3/1/23.

UBA, 2021. Treibhausgasemissionen sinken 2020 um 8,7 Prozent. Available online at https://www.umweltbundesamt.de/presse/pressemitteilungen/treibhausgasemissionen-sinken-2020-um-87-prozent, checked on 2/12/23.

Wilson, C., 2014. Interview techniques for UX practitioners: a user-centered design method. Morgan Kaufmann, Amsterdam; Boston.

Wimmers, A., Madlener, R., 2020. The European Market for Guarantees of Origin for Green Electricity: A Scenario-Based Evaluation of Trading under Uncertainty. DOI: 10.2139/ssrn.3830442.

Yeh, S., Burtraw, D., Sterner, T., Greene, D., 2021. Tradable performance standards in the transportation sector. In *Energy Economics* 102. DOI: 10.1016/j.eneco.2021.105490.

Appendix

Table A.1: Guiding questions for the semi-structured interview

	Guiding question (in the original German)	English translation by the authors
1	Wie läuft der THG Quotenhandel ab?	How does the GHG Quota Trading work?
2	Wie würden Sie die Rolle der Zwischenhändler beschreiben?	How would you describe the role of poolers?
3	Wie beschreiben Sie den Preisbildungsmechanismus? Wer setzt die Preise fest?	How do you describe the pricing mechanism? Who sets the prices?
4	Welche Kritik (positiv und negativ) haben Sie am Instrument „THG Quotenhandel“?	What criticisms (positive and negative) do you have of the "GHG quota trading" instrument?
5	Wo sehen Sie noch Forschungsbedarf?	Where do you see a need for further research?

Table A.2: Overview of the compliance options, stipulated in sect. 37a, para. 5, BImSchG for 2022-2030, as of October 19, 2022

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Used cooking oils and animal fats (upper limit, energetic)	1.9%								
Palm oil (upper limit, energetic)	0.9%	Forbitten							
Advanced biofuels (lower limit, energetic)	0.2%	0.3%	0.4%	0.7%	1.0%	1.7%		2.6%	
	Multiple credit with factor 2 for quantities above the lower limit								
Hydrogen and PtX fuels	Multiple credit with factor 2								
Biogenic hydrogen		Use in road vehicles creditable as of 2023							
Electricity	Multiple credit with factor 3								
UER	Creditable until 2026					Forbidden			
GHG mitigation from previous year	No specifications								
Fossil fuels	Forbidden from 2022								

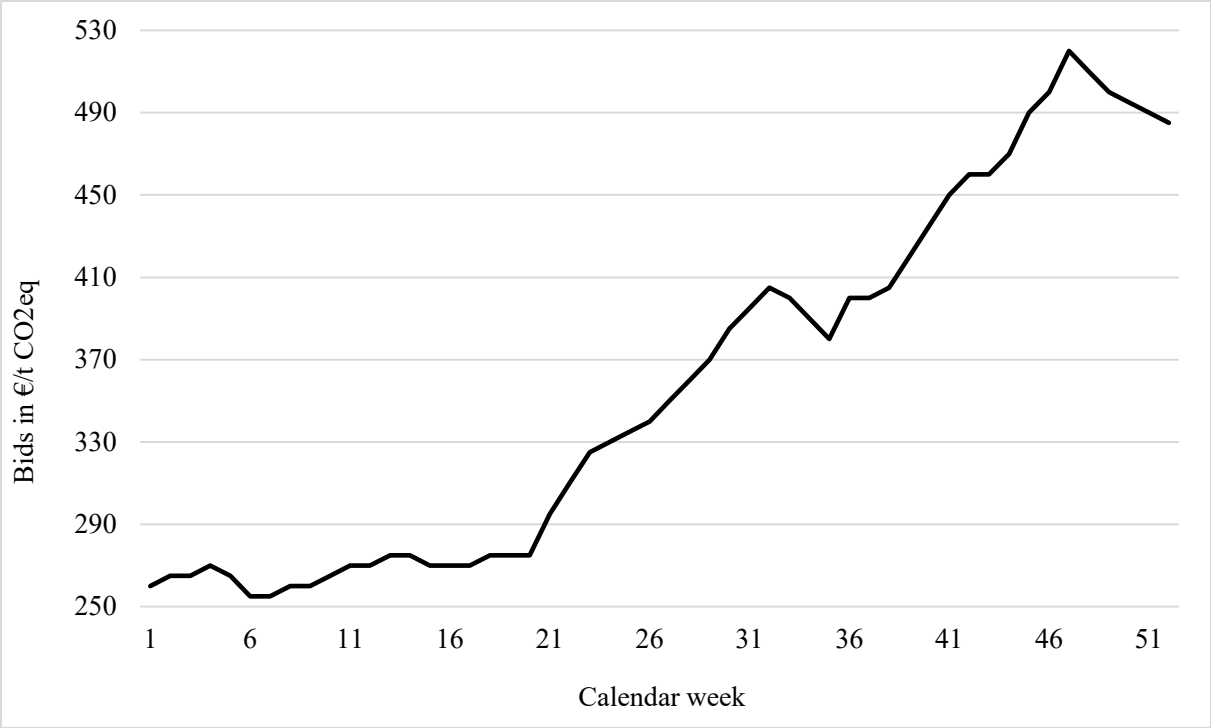

Figure A.1: Bids for the no crop compliance option certificates in Germany in 2021

FCN | Future Energy Consumer Needs and Behavior

E.ON Energy Research Center

RWTH AACHEN UNIVERSITY

List of the latest FCN Working Papers

2023

Scholing F., Madlener R. (2023). Local Flexibility Market Support for Congestion Management in the German Distribution Grid: A Bi-level Optimization Approach, FCN Working Paper No. 1/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Fabianek P., Madlener R. (2023). Assessing Zero-Emission Vehicles from the Customer's Perspective Using a Multi-Criteria Framework, FCN Working Paper No. 2/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Schreiner L., Madlener R. (2023). The Impact of Sustainable Innovation Finance on Achieving Global Climate Goals, FCN Working Paper No. 3/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Hinkenjann B., Madlener R. (2023). Profitability of Biogas Plant Configurations in Germany Considering Scale and Pooled Biogas Upgrading, FCN Working Paper No. 4/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Geschke M. P., Fabianek P., Madlener R. (2023). Loosening the Brakes: An Empirical Analysis of Factors Hindering the Acceptance of Fuel Cell Vehicles in Germany, FCN Working Paper No. 5/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Mallma W., Madlener R. (2023). The Potential of Hydrogen Storage for Photovoltaic Power Generation in Morocco and Cooperation with the EU, FCN Working Paper No. 6/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Müller-Ibold J., Madlener R. (2023). The Economic Potential of Autonomous Hydrogen-Powered Ground Effect Vehicles for Intercontinental Container Shipping, FCN Working Paper No. 7/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Fleiter J., Atasoy A. T., Madlener R. (2023). Household Responses to the Tax Treatment of Income from Solar PV Feed-in in Germany, FCN Working Paper No. 8/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Liepold C., Fabianek P., Madlener R. (2023). Tradable Performance Standards for a Greener Automobile Sector: An Economists' Appraisal of the German Greenhouse Gas Mitigation Quota, FCN Working Paper No. 9/2023, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

2022

Greschke N., Madlener R. (2022). Trading Strategies for Flexibility on the Intraday Power Market, FCN Working Paper No. 1/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Schatke A., Madlener R. (2022). Multi-criteria Evaluation of Citizen Preferences for Energy Cooperatives vs. Crowd Investing: The Case of Solar Photovoltaics in Germany, FCN Working Paper No. 2/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Rogawski J., Madlener R. (2022). Economic Optimization of Selected Distributed Energy Systems and Management Strategies in Industrial Microgrids, FCN Working Paper No. 3/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Qian Y., Madlener R. (2022). A Comparative Study of Econometric and Machine Learning Models for Intraday Electricity Prices in Germany, FCN Working Paper No. 4/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Najarianeraghi K., Madlener R. (2022). Analyzing and Predicting Traded Volumes in Power Markets Using Machine Learning Approaches: A Case Study for the UK, FCN Working Paper No. 5/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Fabianek P., Madlener R. (2022). A Multi-Criteria Assessment Framework for Evaluating the User Experience at E-Vehicle Charging Stations in Germany, FCN Working Paper No. 6/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Herrmann K.P., Madlener R. (2022). Learning Curves and Diffusion Dynamics of Energy-Efficient Public Lighting in Germany, FCN Working Paper No. 7/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Sabadini F., Madlener R. (2022). Smart Grid with Renewable Sources, Electric Vehicles and Storage Systems: Operational and Economic Aspects, FCN Working Paper No. 8/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Sabadini F., Madlener R. (2022). Does Taxation Hamper the Vehicle-to-Grid Business Case? Empirical Evidence from Germany, FCN Working Paper No. 9/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Sabadini F., Madlener R. (2022). Effectiveness of a Serious Game for Teaching and Increasing the Awareness About the German Energy Transition, FCN Working Paper No. 10/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Zemamou M., Madlener R. (2022). Economics of Small-Scale Wind Turbine Systems for Domestic Electricity and Hydrogen Production, FCN Working Paper No. 11/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Schreiner L., Madlener R. (2022). A Green Alliance With the Black Continent: Requirements to Implement a Long-Run EU-Africa Hydrogen Economy via Public-Private Partnerships, FCN Working Paper No. 12/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Croé L., Madlener R. (2022). Regionalized Input-Output Modeling to Assess the Impacts of Energy Transition Investments on the Local Economy, FCN Working Paper No. 13/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Khalid A., Madlener R., Glensk B. (2022). Investment Decisions on Concentrating Solar Power Plants: A Comparative Analysis for Different Solar Irradiation Regions, FCN Working Paper No. 14/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Bierwirth S., Madlener R., Specht J.M. (2022). On the Economics of BECSS: A Comparative Analysis of Different Biomass Feedstocks and Conversion Technologies, FCN Working Paper No. 15/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Heinz F., Madlener R. (2022). The Option Value of Hydrogen Retrofits for Subsidy-Free Offshore Wind Farms, FCN Working Paper No. 16/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Müßel J., Ruhnau O., Madlener R. (2022). Modeling Volatility and Flexibility of Electric Vehicles‘ Energy Consumption, FCN Working Paper No. 17/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised May 2023).

Burg L., Gürses-Tran G., Madlener R. (2022). How Much is it Worth? Assessing the Economic Gains from Increased Electric Load Forecasting Accuracy. FCN Working Paper No. 18/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Croé L., Madlener R. (2022). Explainability and Trust: Addressing Socio-Economic Challenges for AI-based Home Energy Management Systems Regarding End-user Acceptance, FCN Working Paper No. 19/2022, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2021

Fabianek P., Glensk B., Madlener R. (2021). A Sequential Real Options Analysis for Renewable Power-to-Hydrogen Plants in Germany and California, FCN Working Paper No. 1/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Fabianek P., Schrader S., Madlener R. (2021). Techno-Economic Analysis and Optimal Sizing of Hybrid PV-Wind Systems for Hydrogen Production by PEM Electrolysis in California and Germany, FCN Working Paper No. 2/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Karami M., Madlener R. (2021). Business Models for Peer-to-Peer Energy Trading in Germany Based on Households' Beliefs and Preferences, FCN Working Paper No. 3/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March (revised October 2021).

Rasool M., Khalilpur K., Rafiee A., Karimi I., Madlener R. (2021). Evaluation of Alternative Power-to-Chemical Pathways for Renewable Energy Exports, FCN Working Paper No. 4/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised April 2023).

Madlener R., Sheykhha S., Briglauer W. (2021). The Electricity- and CO_2-Saving Potentials Offered by Regulation of European Video-Streaming Services, FCN Working Paper No. 5/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Specht M., Madlener R. (2021). Deep Reinforcement Learning for Optimized Operation of Renewable Energy Assets, FCN Working Paper No. 6/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September (revised April 2022).

Liu X., Madlener R. (2021). Economic Benefits of Direct Current Technology for Private Households and Peer-to-Peer Trading in Germany, FCN Working Paper No. 7/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Schmitz H., Madlener R. (2021). Preferences for Energy Retrofit Investments Among Low-income Renters, FCN Working Paper No. 8/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Burg L., Gürses-Tran G., Madlener R., Monti A. (2021). A New Methodology for Feature and Model Selection for Active Power Prediction in Electrical Grids, FCN Working Paper No. 9/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Atasoy A.T., Schmitz H., Madlener R. (2021). Mechanisms for Rebound Effects of Solar Electricity Prosuming in Germany, FCN Working Paper No. 10/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Karami M., Madlener R. (2021). Sustainability Performance Benchmarking of Rural Municipalities in Germany, FCN Working Paper No. 11/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Barton L., Madlener R. (2021). A Real Options Analysis of the Potential of Ammonia to Decarbonize Maritime Transport, FCN Working Paper No. 12/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Yu Q., Madlener R. (2021). Industrial Utilization or Storage of CO2? A Compound Real Options Valuation for the Retrofitting of Coal-Fired Power Plants, FCN Working Paper No. 13/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Yu Q., Madlener R. (2021). A Fuzzy Real Options Analysis of Investments in Coal-Fired Power Plants Retrofitted with CCS or CCU, FCN Working Paper No. 14/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Wohlan L., Madlener R., Specht M. (2021). A Real Options Analysis of the Siting and Cost-Efficient Layout of Charging Infrastructure for Fuel Cell and Battery Electric Vehicles, FCN Working Paper No. 15/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Sheykhha S., Rane R., Madlener R. (2021). Decarbonization and Sectoral Coupling Between the Energy and Transportation Sectors: An Energy Systems Analysis for Germany, FCN Working Paper No. 16/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

FCN Working Papers have been published since 2008 and are free of charge. They can mostly be downloaded in pdf format from the FCN / E.ON ERC Website (www.eonerc.rwth-aachen.de/fcn) and the SSRN Website (www.ssrn.com), respectively. Alternatively, they may also be ordered as hardcopies from Ms Sabine Schill (Phone: +49 (0) 241-80 49820, E-mail: post_fcn@eonerc.rwth-aachen.de), RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Chair of Energy Economics and Management (Prof. Dr. Reinhard Madlener), Mathieustrasse 10, 52074 Aachen, Germany.