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The European Market for Guarantees of Origin for Green Electricity: A Scenario-Based Evaluation of Trading under Uncertainty

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Abstract

Because electricity is a homogeneous commodity, the origin of a specific MWh of delivered green electricity cannot be determined. Thus, Guarantees of Origin (GoO) were introduced in order to enhance transparency on the origin of production of green electricity in Europe. The separation of electricity and GoO trade has resulted in a prosperous GoO market that is, however, characterized by non-transparency and speculative behavior. Historic price development occurs seemingly arbitrarily and can therefore not be used to forecast future GoO prices. Bearing this in mind, this paper firstly provides an overview of the European GoO market and an analysis of the historic price development; secondly, it proposes a model for determining future price developments of European GoOs for different renewable energy technologies in different countries up to 2040. Four different scenarios are considered. It was found that prices for GoOs will increase on average in the next years, with prices ranging from 1.77 to 3.36 €/MWh in 2040. Coupled with rising demand for green electricity and further standardization of issuance procedures as well as the projected price developments, GoOs might well become a useful tool for the promotion of green electricity production in the EU.

Keywords: renewable energy; green electricity; policy; willingness to pay; power purchase agreement; Europe; guarantees of origin

JEL Classification Nos.: O33, O52, Q42, Q48.

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List of Abbreviations Used

AIB	Association of Issuing Bodies
ATP	Ability-to-pay
CAGR	Compound annual growth rate
EECS	European Energy Certificate System
GoO	Guarantees of Origin
IEA	International Energy Agency
LCOE	Levelized cost of electricity
NACE	Statistical Classification of Economic Activities in the European Community (*nomenclature statistique des activités économiques dans la Communauté européenne*)
OECD	Organisation for Economic Co-operation and Development
PPA	Power purchase agreement
RES	Renewable energy sources
WAVG	Weighted average
WTP	Willingness-to-pay

1. Introduction

To achieve climate neutrality by 2050, as proposed by the European Commission in the European Green Deal of 2019, the production of green electricity, i.e. electricity that has been produced from renewable energy sources such as wind, solar, hydro, or biomass, must be drastically increased (Achtnicht, 2013, p.44; Directive 2009/72/EC, 2009; European Climate Law Proposal, 2020; Sielker et al., 2018, p.259). The liberalization of the European energy market allows consumers to choose their preferred electricity provider and the type of contract, which means that, in addition to producers and regulators, industrial and private consumers can also actively help to achieve the before mentioned target (Mulder & Zomer, 2016, p. 100; Raadal et al., 2012, p.427). Consumers can acquire their green electricity in multiple ways. In Europe, the purchase of so-called *guarantees of origin* (GoOs) requires the least organizational effort and is the least-cost option (IRENA, 2018, pp.41–44).

The GoO concept was introduced in order to prove to consumers that a certain amount of green electricity has in fact been produced, since – as electricity is a homogeneous good – the origin of the supplied electricity cannot be determined (Langeraar & Devos, 2003, p.63). GoOs are thus certificates that can be traded today across most European countries and that are used to disclose green electricity purchases (AIB, 2020c). However, despite the GoO market flourishing and continuing to grow, little information about the market exists and, due to bilateral trading, GoO price levels remain mostly unknown to outsiders (Hauser et al., 2019; IRENA, 2018; Mulder & Zomer, 2016). This lack of transparency has been heavily criticized in the literature and is considered to be the main reason for the perceived ineffectiveness of GoO in promoting green electricity production (Brander et al., 2018; Hufen, 2017; Mulder & Zomer, 2016; Raadal et al., 2012).

Therefore, this paper aims at reducing the non-transparency of the European GoO system by providing a detailed overview and analysis of the member states of the Association of Issuing Bodies (AIB) as well as a scrutiny of historic developments of GoO prices. Additionally, we introduce a model to determine future GoO prices in Europe that is capable of forecasting prices for GoOs of different technologies and origins up to 2040. The benefits of this model are various. For instance, it can be used by regulators to determine whether the GoO system might be in need of reform. Other stakeholders, such as project developers or investors for renewable energy production plants, can use these forecasts to calculate the profitability of their intended projects.

The remainder of this paper is structured as follows. Section 2 gives a brief overview of the concepts of GoO and Willingness-To-Pay (WTP). The related literature is discussed in Section 3, while Section 4 describes the fundamentals of the GoO model used for the policy analysis. In Section 5, the data used to forecast GoO prices are discussed This section also contains a detailed description of the calculations made to determine the consumers' individual and aggregate WTPs and of the scenarios investigated. Section 6 presents the results and a critical discussion. Section 7 concludes and presents some policy implications as well as recommendations for future research.

2. Theoretical Background

Before we introduce our analysis of the European GoO market and our proposed model, some theoretical terminology needs to be provided.

(1) Guarantees of origin. In general, consumers have four options for acquiring green electricity. Presented in the order of their increasing positive impact on green electricity production and additional organizational effort and costs, these are: *unbundled energy attribute certificates* (EAC), p*ower purchase agreements* (PPA), *renewable energy offerings,* and *direct investments for self-consumption* (on-site and off-site) (IRENA, 2018, pp.41–44). Amongst commercial and industrial consumers, EACs have been the most frequently used method for green electricity acquisition (RE100, 2019). The most commonly used type of EACs in the

European Union are GoOs. The basic concept of GoOs will be briefly explained in the following.

As electricity is a homogeneous good, it is impossible to determine the origin of a certain amount of electricity that has been consumed (Langeraar & Devos, 2003, p.62). However, energy providers in Europe must be able to disclose whether the electricity they deliver to consumers has been produced from renewable energy sources and may therefore be labeled as "green" (Directive 2009/72/EC, 2009; Markard & Holt, 2003). For this reason, GoOs were introduced in the European Union in 2001 (Directive 2001/77/EC, 2001; Directive 2009/28/EC, 2009).

The theoretical design of the GoO system will be explained in the following: For every MWh of green electricity that is fed into the grid by a producer, that producer may request the issuance of one GoO in its respective national registry. During its lifetime, this GoO may be traded internationally amongst traders, utilities, and suppliers until it is canceled upon request when the corresponding MWh of green electricity has been sold and must be disclosed to a consumer. If the GoO is not cancelled after 12 months, it expires and is removed from the registry. The corresponding MWh of green electricity is still fed into the grid – the "greenness" of the electricity, however, has not been sold. This separation between the physical delivery of electricity and the trading of GoOs has resulted in the emergence of a fully independent but non-transparent market for GoO trade (AIB, 2020c; Umweltbundesamt, 2020). As this trade can also be conducted on an international basis in the *European Energy Certificate System* (EECS), an acknowledged independent institution is required to ensure the correct processing of GoOs because of different systems diverging from one another in terms of regulations (AIB, 2020c; Langeraar & Devos, 2003). This institution is the Association of Issuing Bodies (AIB), which initially defined – and continues to refine – a regulatory framework in compliance with EU law and the respective national laws (Jansen et al., 2016; Raadal et al., 2012). As of the writing of this paper, the EECS consists of 26 member countries, including non-EU states such as Norway, Iceland, and Switzerland.

As is the case with most other markets, the GoO market is determined by the relation between the two fundamental concepts of supply and demand. In an ideal situation, the supply and demand curves meet at the equilibrium price and quantity. The GoO market, however, is characterized by an oversupply of GoOs, as supply exceeds demand (AIB, 2020a; Woeckener, 2019, pp.81–83). This special situation is illustrated in Fig. 1.

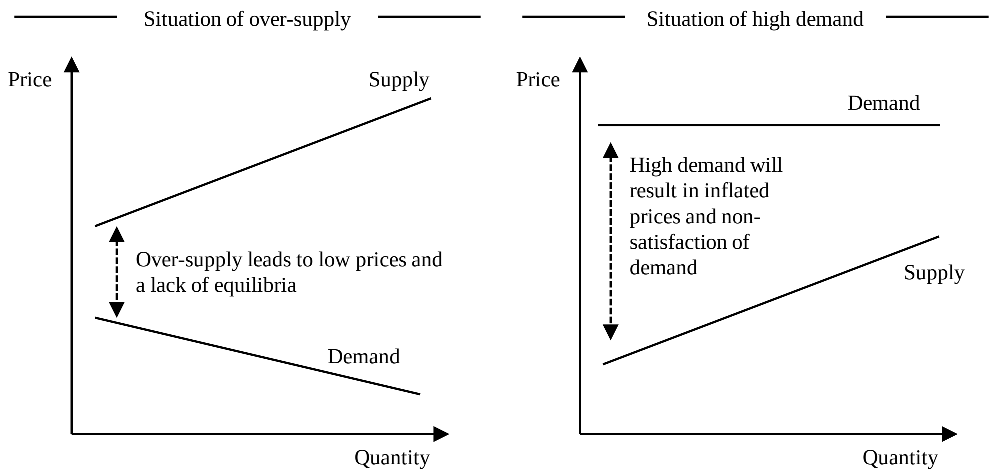

Fig. 1. Impact of supply and demand imbalances on GoO prices

In Fig. 1, supply and demand curves are shown to be linear. This, however, is not the case in reality. The phenomenon that describes the price-dependent shift or the curvature of demand and supply curves is known as price elasticity. Fig. 2 shows three different types of price elasticity for a theoretical supply curve, with the two extremes, i.e. perfectly inelastic and perfectly elastic supply (Parkin et al., 2003, p.97; Varian, 2005, p.270). The case of a change in price elasticity beyond a certain boundary price is shown in Fig. 3.

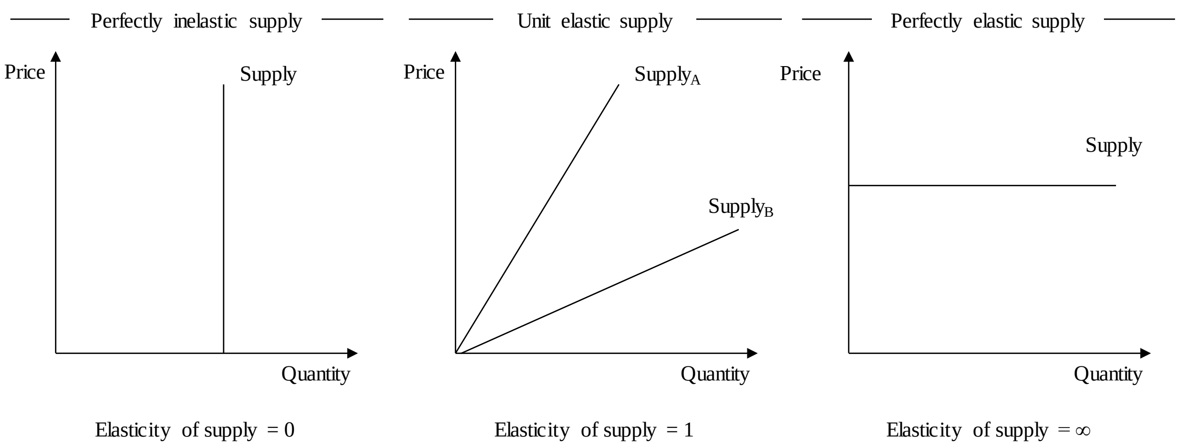

Fig. 2. Price elasticity of GoO supply

Source: Parkin et al. (2003), p.97

(2) Willingness-to-pay. In the literature, WTP is defined in multiple ways. In this paper, the term refers to the maximum price that a consumer is willing to pay for a certain good (Breidert, 2006, p.35)

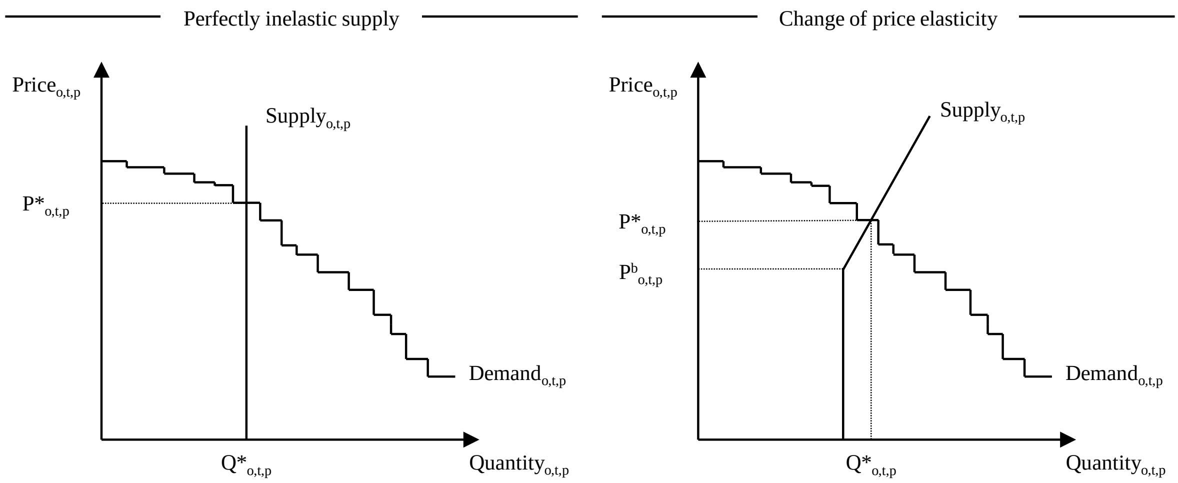

Fig. 3. Price-setting equilibria of different supply elasticities

Generally speaking, two basic methods can be used to determine the WTP. The first option – revealed preferences – is based on market data. The second option – stated preferences – is based on a survey approach (Yevdokimov et al., 2019, p.293). The assumptions made in our analysis are based on revealed preferences, as the survey option was beyond the scope of this research (Hofstetter & Miller, 2009, pp.33–34).

3. Literature Review

In the literature, descriptions of the development and corresponding prices in the European GoO market are still scarce. Most of the literature is concerned with the effectiveness of GoOs in terms of the promotion of additional green electricity production. In this section, we present a summary of this literature and also provide an overview of the literature focusing on the WTP for green electricity. Additionally, we will argue that no literature exists as yet that has attempted to design a price forecast model for European GoOs, which is an original contribution of this paper.

3.1 Critical Evaluation of GoOs in the Literature

The picture of energy production, use, and disclosure that is created by the EECS differs significantly from the actual trading of green electricity (Hufen, 2017, p.10). For example, Iceland produces all of its electricity from renewable energies, with most of it resulting in GoOs being issued within the EECS system. However, Iceland has no physical connection to the European electricity grid. Therefore, green energy that is produced in Iceland and issued as GoOs cannot in any way count as continental European green electricity, nor can it have a positive impact on the production of renewable energy in continental Europe (Hufen, 2017, p.10; Mulder & Zomer, 2016, p.102). The same applies for other Scandinavian countries, such as Norway, where consumers, due to their knowledge of a domestic electricity mix based solely on hydro power, have no interest in buying GoOs and thus paying extra for green electricity (Winther & Ericson, 2013, p.382).

As will be shown in Section 4, many AIB member states allow the issuance of GoOs for supported energy, thus increasing the risk of double counting. This occurs when the perception arises that an amount of green electricity has been certified or traded twice, and it can result in further distrust of the system. It has therefore been heavily criticized in the past (Mulder & Zomer, 2016, p. 106; Ragwitz et al., 2009, p. 305). This perceived issue of double counting could perhaps be tackled by introducing mandatory cancelation of supported GoOs and by further harmonizing the EECS system amongst AIB member states (Jansen, 2017, p.4; Winther & Ericson, 2013, p.382).

Another significant disadvantage of the current GoO system in Europe is its low price level. Although official information on GoO prices is not publicly available, it is known that prices for hydro GoOs have ranged from 0.05 € per MWh to 0.5 € per MWh in the last few years up to an average of 1.5 € per MWh in 2018 (Hauser et al., 2019, p.214; Klimscheffskij et al., 2015, p.4672). These prices provide an additional stream of revenue for producers, but they are too low to trigger significant investments in renewable energy production (Mulder & Zomer, 2016, p. 106; Raadal et al., 2012, p.421).

In conclusion, the perception arises that GoOs in general have no impact on the increase of renewable energy production and are, therefore, a tool that is used solely for electricity disclosure and marketing purposes (Brander et al., 2018, p.31; Hauser et al., 2019, p.70; Hufen, 2017, p.9; Jansen, 2017, p.3; Mulder & Zomer, 2016, p.101; Nordenstam et al., 2018, p.210; Umweltbundesamt, 2012, p.5).

This makes perfect sense, as the first and foremost reason for the introduction of GoOs was that of electricity disclosure (Directive 2009/28/EC, 2009, § 15). For this purpose, they are an essential tool and they generally fulfil that purpose, although, as mentioned above, a few issues are still at hand concerning harmonization and transparency (Hauser et al., 2019, pp.80–81). Additionally, GoOs are necessary because the acceptance of renewable electricity production and the transition to carbon-neutral economies is based mainly on information (Sundt & Rehdanz, 2015, p.14). But apart from disclosure, GoOs can also be used in greenhouse gases (GHG) protocols and might therefore be used to improve GHG inventories and the carbon footprints of companies and households (Jansen et al., 2016, p.2; Nordenstam et al., 2018, p.203; Raadal et al., 2012, p.425; Sotos, 2015, p.84).

Another advantage of GoOs is the possibility to generate additional income for producers. In countries that allow the issuance of GoOs in addition to the reception of financial support for RES production, revenue generated from trading GoOs is a highly welcomed source of income, provided that the registry fees are sufficiently low[1] (Nordenstam et al., 2018, p. 206; Raadal et al., 2012, p.424).

The above-mentioned lack of increased incentive for green electricity production through GoOs can be addressed when GoO prices are analyzed closely. Once it becomes more economically viable to issue GoOs than to use national subsidies for RES production, GoOs will have a positive impact on the production of renewable energy (Jansen, 2017, p.4; Mulder & Zomer, 2016, p.106). GoO prices are influenced by the age and technology of a power plant as well as its location (Hauser et al., 2019, pp.210–211; Raadal et al., 2012, p. 424). The most influential aspect, however, is the fundamental concept of supply and demand (Jansen et al., 2016, p. 5). Over the last years, the European demand for green electricity has been lower than supply, as can be seen by the expiry of GoOs in the EECS, and this has resulted in low prices (AIB, 2019a, p.12). Thus, in theory, once demand for GoOs increases, prices will rise and therefore result in GoOs becoming a potential tool for the promotion of renewable energy production (Hauser et al., 2019, p.217; Umweltbundesamt, 2012, p.5). As interested consumers are willing to pay higher electricity prices in exchange for higher amounts of renewable energy in their supply mixes, and as corporate awareness is increasing as well as a more active approach being conducted in terms of energy acquisition, the necessary demand for GoOs could be generated if European policy makers were to pave the way (IRENA, 2018, p.15; Raadal et al., 2012, p.427; RE100, 2019, p.8; Sundt & Rehdanz, 2015, p.5; Winther & Ericson, 2013, p.382; Yang et al., 2015, p.24).

Whether GoOs are seen as an additional revenue option – or even as an alternative to subsidies for new projects – is highly dependent on the decision makers involved. While project developers, wishing to maximize their profits, will value the possibility of GoO issuance in their project planning, investors and especially lenders will not value such issuance as highly without the security of long-term contracts. Additionally, the size of the project also decides whether GoOs are of importance or not (Holt et al., 2011, p.37; Raadal et al., 2012, p.424).

In conclusion, the current GoO system design is able to fulfil its original purpose of electricity disclosure. However, due to low prices and a lack of harmonization amongst EECS member states, GoOs can currently not be regarded as an effective instrument for the promotion

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[1]For details of current fees in the national registries, see AIB (2020b).

of the production of green electricity. However, once prices exceed national support schemes and further harmonization eventually leads to the elimination of double-counting – and thus an increase of trust inthe GoO scheme – GoOs might become a useful instrument for the EU-wide transitioning to a carbon-neutral economy by 2050.

3.2 Price Information and Evaluation in the Literature

As this paper proposes a model for forecasting GoO prices, an analysis of historic GoO prices was conducted. This analysis consists of information from the literature and from commercial providers of price information about European GoOs. A summary of these prices can be found in Table A-1 of the Appendix.

GoOs issued for Nordic Hydro, i.e. for green electricity generated in Denmark, Finland, Iceland, Sweden, or Norway, are used as a bottom benchmark for prices (Gaia Consulting Oy, 2011, p.16; Hauser et al., 2019, p.213). Therefore, most price analyses and information available focus solely on Nordic Hydro prices. As stated in Subsection 2.2.6, prices are influenced by several factors, such as the age of the producing power plant, the origin, and the technology. Consequently, prices for different types of GoOs can vary.

Since the introduction of the EECS, prices have been relatively stable for most of the time. Nordic Hydro GoOs were traded for prices ranging from 0.05 €/MWh to approx. 0.5 €/MWh (Klimscheffskij et al., 2015, p.4672; Oslo Economics, 2018, p.21). In 2017, prices for Nordic Hydro remained in the previously seen ranges from 0.22 €/MWh to 0.38 €/MWh (Dagoumas & Koltsaklis, 2017, p.65; Hauser et al., 2019, p.213). However, in 2018, prices exceeded 1.15 €/MWh and certain Nordic Hydro types, especially GoOs coming from power plants no older than six years (labeled as “new”), were traded for up to 4 €/MWh (Hauser et al., 2019, pp. 214–216). From 2012 to 2016, prices for Dutch wind and solar GoOs rose considerably (Hufen, 2017, p.13). They continued to do so and in September 2018, prices for Dutch wind exceeded nearly all previously seen prices for GoOs by peaking at just above 8 €/MWh (Münster, 2019). Only Swiss PV reached higher price levels of up to 14.3 €/MWh (Advantag Services GmbH, 2019). At the time of writing and based on the available information, most prices have returned to their respective pre-2018 levels (Greenfact, 2020, pp.16–17; Nvalue AG, 2020).

As can be seen by the rise and fall of prices in the last three years, GoO prices are highly volatile and are apparently subject to market speculation. Price increases in 2011 are likely to have resulted in speculations regarding the increase of RES production in the wake of the Fukushima nuclear plant disaster (Münster, 2019; Oslo Economics, 2018, p.21). Another rise in prices was noted in the wake of miscommunications when the United Kingdom’s unconstrained trade in GoOs occurred (Oslo Economics, 2018, p.21). The dramatic increase of all price levels in the summer of 2018 probably resulted from the drought situation in Europe and the perceived lack of available hydropower (Hauser et al., 2019, p.216; Münster, 2019). Because Nordic Hydro GoOs are perceived as the lower price boundary, most other prices are also likely to have increased.

In the Netherlands, GoOs have been branded as "cheat products" by societal organizations due to the perceived fact that GoOs create no incentives to increase renewable energy production but give the impression that the green electricity has been locally produced when it is disclosed on domestic electricity bills. This has resulted in a high demand for local, i.e. Dutch, GoOs, thus driving Dutch GoO prices upwards. (Hufen, 2017, pp.13-14) Additionally, a high awareness of climate change and a functioning CO_2 reduction and disclosure system in the Netherlands might have had an additional impact on Dutch price levels (Münster, 2019). More details on the prices described here can be found in Table A-1.

3.3 Willingness-To-Pay

The determination of WTP is a central part of this model. However, the academic literature typically focuses solely on the WTP for green electricity itself, and here mostly on that of household consumers. Some of the assumptions mentioned in this section will become relevant when the data are presented later in this paper and will thus not be neglected here.

In a study conducted by the OECD (2014, p.102), over 60% of consumers stated that they were willing to pay more for electricity from renewable sources than for electricity from conventional sources. This is supported by (Yang et al., 2015, p.24), who found that apart from highly price-sensitive consumers, value seeking and so-called "green consumers" are willing to pay higher electricity prices for an increase in the share of renewable energy in their respective energy mix. In their meta-analysis, Sundt & Rehdanz, 2015, p.7 found that, in general, people are willing to pay higher prices for green electricity. These consumers tend to be younger, to live in urban areas, and to be members of an environmental organization. They also express a higher concern for environmental issues than other questioned participants (OECD, 2014, p.102). In their study, Roe et al. (2001, pp.919-922) find that the WTP for an increase of renewable energy in the consumer fuel mix depends on education, income, and knowledge of environmental matters. Consumers with a university-entrance qualification or a higher income, and those who are members of an environmental organization, tend to be willing to pay more for an increase in green electricity production and pollution reduction than others. Soon & Ahmad (2015, p.885) found that WTP for green electricity varies depending on knowledge, information, awareness, and exposure to renewable energies and green electricity production. Diaz-Rainey & Ashton (2011, p.4671) label these indicators as "attitudinal" and find that consumers with higher WTP for green electricity have a higher income, are better informed with respect to energy matters, and, as already stated above in the other findings, show concern for the environment. It is therefore evident that the WTP for green electricity depends on socio-economic factors and varies between different consumer and household groups (Bollino, 2009, p.95; Soon & Ahmad, 2015, p.885).

The type of fuel from which the offered green electricity is generated also has an influence on the WTP. In his meta-analysis that compared worldwide studies, Grilli (2017, pp.258–259) finds that consumers have the lowest WTP for electricity generated from hydropower. Wind, solar, biomass, and mixed sources have similar values, whereas consumers are most willing to pay for green electricity generated from geothermal energy. Borchers et al. (2007, p.3333) come to similar results. Here, consumers have the highest WTP for electricity generated from solar power. Mixed, or "generic green" sources, have the second-highest WTP, while wind and biomass are seen as the least valuable from a consumer's point of view. These WTP ranks correspond to observed historic GoO prices, where GoOs for hydropower mark the lower price boundary (Soon & Ahmad, 2015, p.881).

However, it should be noted that the WTP for green electricity is limited (Hufen, 2017, p.14). In their study, Andor et al. (2017, p.225) compared several WTP data sets from Germany and conclude that WTP for green electricity, at least in Germany, is in fact declining. This is somewhat supported by Winther & Ericson (2013, p.382), who note that Europe as a whole is failing to significantly increase consumer WTP for green electricity. Yevdomikov et al. (2019, p.301), however, estimate the development of the WTP of urban residential electricity consumers in Canada from 1991 to 2013 and find that the WTP for green electricity has been steadily increasing since 2005. The same can be said for Italian consumers who are, in general, willing to support Italian efforts to increase the production of green electricity through higher prices (Bigerna & Polinori, 2014, pp.117-188; Bollino, 2009, p.95). In their meta-analysis, Soon & Ahmad (2015, p. 885) state that, on a global average, WTP for green electricity is in fact increasing.

In this section, it was shown that the focus of literature on GoOs lies on their effectiveness in promoting additional green electricity production. By providing an overview of historic prices, we show that prices are not formed by traditional market behavior but that they rather underlie the speculations of market participants. This shows that future prices cannot be predicted by analyzing past data but instead must be derived from a model design that is shown in the following section. Additionally, literature studying WTP for such electricity is limited mostly to private household consumers. However, some studies, especially where WTPs for different technologies are evaluated, will be a helpful source of information for this paper's model.

4. Model Specification

According to Velazquez Abad & Dodds (2020, p.11), the value of a GoO depends on the size of the market, the demand for green electricity or tariffs, and the question of whether disclosure is mandatory and, if so, whether the disclosure scheme is also mandatory for complementary subsidy schemes. All of this information is accounted for in the model. However, to reduce complexity, some assumptions are necessary, as shown in the following section.

4.1 Model Assumptions

The here listed assumptions focus on limiting the model's scope and apply to all four scenarios considered. In Section 5, where the scenarios are defined, assumptions regarding the data and specific scenarios will be provided. All assumptions are discussed further in Section 6 when the model's limitations are scrutinized.

The first assumption focuses on the issuance of GoOs in the market. As can be seen by regarding the consistent amount of GoOs that expire after their respective lifetimes of 12 months, producers issue GoOs regardless of the question of whether they will be able to sell them (AIB Acticity statistics; AIB 2020a). This leads to the assumption that system costs are negligible, although some registries do charge fees for the issuance and trade of GoOs (AIB Service Fees; AIB 2020b). Therefore, for a given point in time, supply is assumed to be perfectly inelastic. This results in the issuance of GoOs whenever possible, although they might not all be sold.

For the model to function, an equilibrium price must be found. This can only be achieved when demand exceeds supply. Therefore, it is assumed that demand exceeds supply from a certain year onwards. This depends on the expected development of the demand. As of today, as can be seen by the amount of expiring GoOs, this is not the case.

Currently, prices for the least-desired GoOs, Nordic Hydro, lie at about 0.2 €/MWh (see Table A-1). In our model, prices are determined by the lowest WTP that may lie below past minimum prices. Thus, the fact that GoOs seem to have a lower price boundary is neglected.

Because consumers are assumed to aim at cost minimization, GoOs with prices above the lowest levelized cost of electricity (LCOE) will not be purchased, as it would then be cheaper for consumers to acquire their electricity through other options. Therefore, GoO prices are assumed to not exceed the lowest LCOE values in a given year. These values are determined by the LCOE for wind or solar photovoltaics, as these technologies are expected to have the lowest LCOE (IRENA, 2019, p.21, 2020, pp.15-17).

Due to limited insight into the GoO market and the lack of knowledge regarding the age of the issuing power plants, GoOs are only differentiated from one another by their country of origin and the corresponding technology.

The WTP values that ultimately determine the prices of future GoOs are determined through an analysis of past data. Calculations and assumptions regarding the future change of WTP for GoOs would add further uncertainty to the model. Therefore, calculated WTPs for GoOs of certain consumers remain constant over the complete timeframe considered.

A similar assumption concerns the demographic change that is likely to occur over the model's timeframe. In this case, the sectors whose data are used do not change demographically. However, their future electricity consumption will be changing according to the literature; some recent developments are discussed in the next sections.

As annual periodicity is the lowest common denominator in most available data, all information and results will be provided on a yearly basis. This also allows the model to neglect the fact that GoOs from a certain production year are carried over into the next year if they are not cancelled or expired.

4.2 Model Definition

According to Raadal et al. (2012, p.424), who state that demand for GoOs and resulting prices are, ultimately, mainly determined by individual consumers' preferences, in the model presented here, prices are determined by the relation between the supply and demand for green electricity. The latter is influenced by the corresponding WTP.

With supply being assumed to be perfectly inelastic, the price must be derived solely from the demand curve in the supply-demand diagram. Without detailed market insight, the exact determination of the future demand curve for a certain GoO type at a certain point in time is a significant challenge and is therefore assumed on the basis of the WTP and on the expected demand of individual consumers. The process will be briefly explained in the following. Fig. A- 1 provides an overview of the information and the variables that are taken into account in the model.

In a first step, the supply of a certain type of GoO for a certain point in time must be determined. Due to data limitations, GoOs are only differentiated according to their origin o and production technology t, e.g. Spanish solar or French biomass. The supply is determined by the amount of GoOs that are issued during some time period p.

Secondly, prices are also determined by the demand of a good. Furthermore, the WTP of a consumer *k* for a GoO of origin *o* and technology *t* must be determined. This is done by determining a consumer *k*'s ability-to-pay (ATP) and that consumer's environmental concern. The ATP is calculated as the ratio between *k*'s costs for electricity and *k*'s profit. Thus, the ATP can be interpreted as the amount that *k* is theoretically able to pay for green electricity. The second factor, environmental concern, is based on estimations depending on *k*'s sector. Once both values are determined, the maximum WTP of *k* can be established by finding the corresponding percentage, as demonstrated in Fig. 4.

Here, the theoretical process is shown for four fictional consumers A, B, C, and D. A has the lowest environmental concern but a high ATP and is therefore willing to pay 10% extra for green electricity. B has the lowest ATP but is still willing to invest a little into the acquisition of green electricity certificates. C has the highest values for both factors and will therefore have the highest WTP. These percentages are then applied to the respective electricity prices in €/kWh in order to get a WTP value in a comparable unit to the GoOs, which are given in €/MWh. Then, the maximum WTP values determined for each consumer are multiplied by derating factors in order to mirror consumer preferences for origin and technology of GoOs.

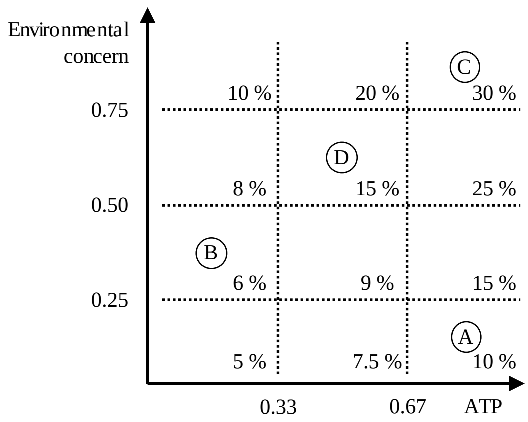

Fig. 4. WTP estimation for exemplary consumers A, B, C, and D

Abbreviation: ATP = Ability-to-pay

Once all the necessary data have been acquired in the required degree of detail, the estimated WTP are sorted in descending order. Then, the demand of the consumer with the highest WTP for a GoO of origin *o* and technology *t* is satisfied first. In this example, this would correspond to consumer C. Once this demand is satisfied, demand corresponding to the second-highest WTP, in this case WTP_D, is satisfied. This is repeated until the supply of this type of GoO has been used up. The equilibrium price $P^*{o,t,p}$ of a GoO of origin *o* and technology *t* in a period *p* is the smallest WTP that corresponds to the consumer who was able to satisfy at least one MWh of their demand. This demand is then decreased by the amount of acquired GoOs of this type and satisfied by GoOs corresponding to the next-lowest WTP of this specific consumer. This process is repeated for every type of GoO. Thus, the demand curve follows a step function characteristic, as shown in Fig. 5.

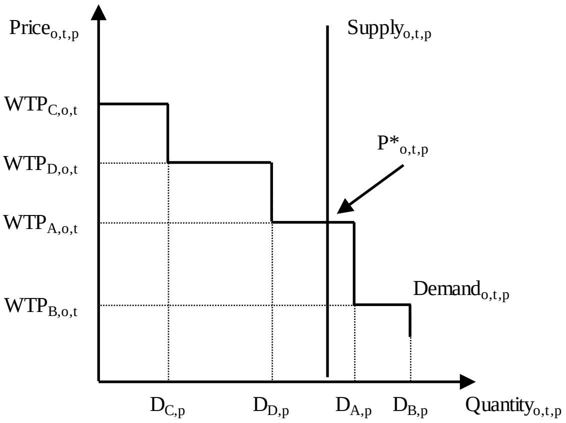

Fig. 5. Determination of the equilibrium price $P^*{o,t,p}$

This mechanism can only function properly if demand exceeds supply at some point. However, currently, the EECS is characterized by an oversupply of GoOs, as can be observed by the ongoing expiry of GoOs after their respective lifetimes of 12 months. Note that for certain types of GoOs, this is already fulfilled from the first period onwards.

The model was implemented in the open-source programming language Python. The program code is provided in Annex 1.

4.2.1. Description of the input data

In total, the market for GoOs has been growing since its introduction in 2002 and is expected to continue to do so in the future (Jansen et al., 2016, p.2; RECS International, 2019, p.9). All GoO data that were used are publicly available on the AIB website. Note that the data provided to the AIB by its member states is inconsistent, because some countries report fully on cancelation, but neglect reporting on issuance (AIB, 2020a). For this model, data up until August 2020 were considered. The degree of detail varies, depending on the year that the data refer to. Information on the total amount of issued, cancelled, expired, and traded GoOs is available on a monthly basis from 2002 to 2020 for every member country and every fuel type, respectively. However, these data were provided separately from one another. Thus, for the years prior to 2016, an analysis on the type of GoOs handled in a specific country's registry was not possible. From 2016 onwards, data on individual countries' issuance, trade, cancellation were available on a monthly basis.

GoO data are provided in two different ways. The first – so-called production statistics – refer to the month and year when the electricity was produced. The second type of data – transaction statistics – refers to the month and year when the transaction of the GoO took place. While production statistics only include issuance, expiry, and cancelation data, transaction statistics also provide information on import, export, and internal trade. For this model, the amount of GoOs currently existent in the registries connected to the AIB Hub was relevant. As transaction statistics refer to the action that was performed in the respective registry as well as the point in time when it took place, and because trade of GoOs is based on the amount of GoOs in the registries, the following analyses were conducted with transaction data (AIB, 2020a). Following Kuronen & Lehtovaara (2017, p.23), a shifted calculation approach was used for the cancelation data. For this paper, the EECS member countries were divided into six categories, depending on their regulations regarding the issuance of GoOs, see Table 1). This gives an indication of the level of regulation and harmonization in and amongst AIB member states. Although the total amount of cancelled GoOs has been steadily increasing over the years, most cancelations and issuances are conducted by only a few countries from varying categories. The three countries with the highest cancellations (based on the shifting approach described above) in 2019 were Germany (15.86%), Spain (12.04%), and Norway (10.54%). Interestingly, Norway and Spain were both amongst those countries with the highest amount of issued GoOs, with 18.80% and 14.38% of total issued GoOs, respectively. Italy had the third highest amount of issued GoOs: 12.93%.

Table 1. Categorization of EECS member countries and GoO systems introduced

Category	Description	Countries
1	Issuance of subsidized electricity, but disclosure on GoO	Austria, Denmark, Estonia, Finland, Italy, Portugal, Switzerland
2	Subsidized GoOs are auctioned	France, Luxembourg, Slovenia, the Slovak Republic
3	Subsidized GoOs are immediately canceled	Cyprus, Lithuania
4	No regulations on subsidies	Belgium, Croatia, the Czech Republic, Greece, the Netherlands, Norway, Spain, Sweden
5	No issuance of supported GoOs	Germany, Ireland, Serbia
6	No subsidy system in place	Iceland

Issue rates, i.e. the share of issued GoOs in green electricity production, vary between technologies and categories, as shown in Table 2.

Table 2. Share of GoOs issued relative to green power production, by category and technology

Category	1	2	3	4	5	6
Biomass	0.64	0.26	0.08	0.49	0.21	No GoO issuance
Geothermal	0.52	0.03	No GoO issuance	No GoO issuance	No GoO issuance	0.92
Hydro	0.78	0.49	0.35	0.6	0.63	0.98
Solar	0.53	0.05	No GoO issuance	0.37	0.02	No GoO issuance
Wind	0.68	0.28	0.5	0.73	0.09	No GoO issuance

Abbreviations: AIB = Association of Issuing Bodies; GoO = Guarantee of Origin

Sources: Own calculations based on data from (AIB, 2020a) and (Eurostat, 2020c)

The results of a more detailed analysis of the GoO market in terms of issuance, cancelation, trade behavior (i.e. whether the country acts as a trade hub due to low transaction fees), and further parameters can be found in Table A-4. This will help to understand the categorization of the countries. Note that for the determination of the input data for the model, the assumed amount of future GoO volumes per country and technology must be calculated first.

4.2.2 ATP-WTP data

To determine the future demand for GoOs of European companies, the approach of identifying the electricity demand of European companies based on their respective sizes and sectors was chosen. In a first step, structural data on European industry was acquired from Eurostat's table "sbs_sc_ind_r2" for the years 2005 to 2017 (Eurostat, 2020b). This table includes information on the average revenue and number of companies of a specific NACE sector and size. For this study, data were limited to Level 2 NACE-Sectors. Five categories of sizes exist: 0 to 9, 10 to 19, 20 to 49, 50 to 249, and over 250 employees. Data on industrial electricity consumption were taken from the table "nrg_cb_e" and from the Swiss Federal Energy Office (Eurostat, 2020e; Swiss Federal Office of Energy, 2020). In the Eurostat table, the industry sector is split into other categories than NACE sectors. Therefore, in a first step, the sectors needed to be matched to be able to compare revenue and number of companies with the respective electricity consumption. This was done following the Energy Balance Guide provided by (Eurostat, 2019, pp.31-34). For this study, sectors corresponding to the Level 2 NACE sectors were chosen. This was done to reduce the amount of data. Consequently, the energy sectors describing the manufacturing of iron and steel and other metals had to be combined. In a next step, the average electricity consumption per NACE sector was calculated on the country level by weighting the consumption provided in the energy balance with the respective revenues. Then, the consumption per NACE sector was divided amongst the different size categories according to the respective proportions of total sector revenue. By dividing the resulting values by the number of companies of a specific NACE sector of a specific size in a specific country, the average electricity consumption of the company in question was determined. Next, average electricity prices were analyzed. This data were taken from Eurostat's table "nrg_pc_25" (Eurostat, 2020a). Here, consumption-dependent electricity prices are provided on a country level. Different values are given, depending on the inclusion of taxes and levies. Swiss data were again taken from a different source (Swiss Federal Office of Energy, 2020, p.45). Finally, these data were matched to the afore-calculated average electricity consumption per sector, size, and country to determine the average electricity costs. These calculations provided the model with values for the average electricity demand of industrial and private consumers in Europe up until 2017. As mentioned above, household demand was determined on a similar basis. Energy data could be more easily matched to households, as only a single energy sector from "nrg_cb_e" corresponds to household consumption. The distribution of these values per country was spread across the three household types (Eurostat, 2020d). Data on Swiss households' energy consumption were taken from a separate Swiss database (Swiss Federal Office of Energy, 2020, p. 26). As Swiss demographic data were not available to the same degree as for other European countries, the distribution for Swiss households was assumed to be the same as for the Austrian data.

For this study's model, future electricity demand had to be determined. But, as a further detailed analysis of the expected development of individual NACE sectors and household demand in Europe is clearly beyond the scope of this study, the estimation of future demand is based on assumptions in the "Stated Policy Scenario" in the IEA's current World Energy Outlook that was made for the general development of the European economy's electricity demand (IEA, 2020, pp.217-218). As the IEA only provides a projection up to 2040, this model will also only cover the timeframe from 2020 to 2040. Using this model's data, these assumptions result in a total electricity demand of 2589.91 TWh in 2020 that grows to approximately 6179 TWh in 2040. As this exceeds green electricity generation in Europe and consequently the amount of GoOs that is assumed to total about 620.7 TWh in 2020, the assumed demand for green electricity from GoOs is reduced to 558.63 TWh (21.57% of total demand). This is done, as a too highly estimated demand would result in highly unrealistic prices. By 2040, it is assumed that 50% of total electricity demand will be covered by GoOs, resulting in a compound annual growth rate (CAGR) of 9% for the initial demand.

It was decided to base the estimation on a variation of the revealed preference method, basing the WTP assumptions solely on structural data provided by Eurostat. The WTP for green electricity, and therefore in some sense GoOs, was determined by analyzing the ability-to-pay (ATP) of an average company of a specific sector and size in a certain country and its environmental concern. The ATP expresses the ability of a company to invest additional money into the acquisition of green electricity. It was calculated as the ratio of profit and electricity costs. Both values were taken from Eurostat data (Eurostat, 2020a, 2020b, 2020e). The second indicator, environmental concern, was estimated based on assumptions of the different NACE sectors' exposure to environmentally concerned consumers, private or commercial. For example, companies belonging to the sector "Manufacturing of cast iron tubes" are likely to have less concern for environmental issues than companies in the sector "Manufacture of food products and beverages". Sectors that had representatives in the RE100-iniative were assumed to have a higher environmental concern, depending on their respective goals (RE100, 2020). The values used for this analysis can be found in Table A-3 in the Appendix.

The WTP of an average company of a certain size in a specific sector in a certain country is therefore dependent on the ratio of ATP and its environmental concern. In this case, the WTP is determined as a discrete percentage value that is then multiplied by the corresponding electricity price to determine the WTP in €/MWh (Eurostat, 2020a; Swiss Federal Office of Energy, 2020). This is necessary, because one GoO corresponds to one MWh of green electricity. A detailed description of the procedure is given in Subsection 4.2. The WTP for European households was taken from (OECD, 2014, pp.102–103).

The obtained WTP values can be seen as the maximum price that an average company of a specific sector and size or a household in a certain country is willing to pay extra for the acquisition of green electricity in general. As prices for GoOs must be paid on top of electricity prices and GoOs are the least attractive form of green electricity acquisition (see Subsection 2.1.2), these WTP values are reduced for households, see Table A-2. Industry WTPs are already estimated at similar rates in the calculation, see Table 3. These values must be multiplied by electricity costs to receive a value in €/MWh. Additionally, as WTP values are determined for a single kWh and transformed to values for per MWh, WTP values greatly exceed the LCOE values that will be used as upper price boundaries (see Subsection 4.1). Therefore, after multiple test runs, a correction factor of 0.15 was applied to the WTP values for model calibration.

Table 3. WTP values for industrial and commercial consumers

Environmental concern	ATP				
	< 20%	< 40%	< 60%	< 80%	< 100%
< 20%	0	0.025	0.05	0.075	0.1
< 40%	0.025	0.05625	0.0875	0.11875	0.15
< 60%	0.075	0.11875	0.1625	0.20625	0.25
< 80%	0.15	0.2125	0.275	0.3375	0.4
< 100%	0.1	0.15	0.2	0.25	0.3

Abbreviations used: ATP = Ability-To-Pay; WTP = Willingness-To-Pay

5. Results

In this model, four scenarios were considered. Each scenario had different assumptions on future RES generation and the regulations of the GoO market. In the following, each scenario's most interesting results will be explained before offering a direct comparison of the results. Thedescription of each scenario's respective results follows the same pattern. First, the issuance of GoOs will be regarded. This gives an indication of the different volumes of GoOs that might be seen in the future EECS. Then, selected future prices are investigated on the country and technology level, respectively. These prices are shown as weighted averages (WAVG), i.e. average prices are calculated based on the proportion of respective GoO types in the total amount of issued GoOs. Additionally, annual growth rates depicted by the CAGR are calculated.

5.1 Scenario 1: Status Quo

In the first scenario, it is assumed that regulations in the AIB regarding harmonization were not put in place. Additionally, countries would not increase their RES production by introducing new technologies if they had not used that certain technology before. Industry demand and electricity supply would follow the IEA's stated policy scenario.

In the beginning of the scenario, i.e. in 2020, the future issuance of GoOs is expected to slightly decline from 2019 levels of about 750 TWh (AIB, 2020a). Due to the calculation method that was based on average issue rates per country, the total expected issuance of GoOs for 2020 amounts to approximately 621 TWh.

In 2020, the most issued GoOs were French hydro GoOs with a total of 112.35 TWh, followed by Norwegian hydro at 57.93 TWh, and Spanish wind at 54.03 TWh. Amongst the ten most issued GoOs in 2020, only two technologies were represented, namely hydro (six out of ten) and wind (four out of ten). The first mentioning of another technology, Italian solar, could be found on rank 16 with a total of 12.91 TWh. Of the GoOs being issued in 2020, Serbian solar had the lowest amount at 568 MWh. Of the 152 possible types of GoOs that could have been issued, only 66 were. This would change in 2025, when, following the defined assumptions, countries would begin issuing GoOs for technologies that they had been using for green electricity production, but had not yet issued GoOs for in the past. Thus, from 2025 onwards, 99 types of GoOs were being issued. By 2025, Italian hydro had surpassed Norwegian hydro, with 75.94 TWh and 74.79 TWh, respectively. French hydro GoOs would remain the most issued type throughout the whole scenario. In 2025, the least amount of GoOs issued corresponded to Icelandic wind with only 1.58 MWh. The second-to-lowest amount of 454.68 MWh were GoOs of the type Slovakian wind. In total, approximately 931.85 TWh of GoOs were issued in 2025. By 2040, the final year of the model's scope, GoO had more than doubled compared to values from 2020: 1626 TWh had been issued. By then, French wind had taken the second place away from Italian hydro. The technology mix amongst the ten most issued GoOs remained the same compared to 2020, with six hydro and four wind GoOs from varying origin countries. In 2020, Irish GoOs were the most expensive with prices of 3.84 €/MWh, followed by GoOs from Luxembourg at 3.15 €/MWh and Serbian GoOs at 3.26 €/MWh. GoO types with the highest issuance volumes, i.e. French, Italian, and Norwegian GoOs, reached average price levels of 0.92 €/MWh, 2.11 €/MWh and 0.03 €/MWh, respectively. By 2025, most prices had increased steadily. Irish GoO prices, however, jumped from 3.91 €/MWh in 2024 to 5.41 €/MWh in 2025. At the same time, Serbian prices plummeted from 3.26 €/MWh to 0.95 €/MWh, resulting in a negative CAGR for Serbian GoOs. The average CAGR was 4.69%.

Just as was done for prices per country, prices per technology were also made comparable by calculating the WAVG. Per model definition, scarce GoO types achieve higher prices than abundant types, see Subsection 4.2. Thus, it was expected that Geothermal GoOs would reach the highest price level. Hydro GoOs were to have the lowest prices, on average. This was fulfilled over the twenty years that were observed, as Geothermal prices increased from an initial 5.12 €/MWh to 12.54 €/MWh in 2040. Hydro GoOs experienced the highest growth rate with a CAGR of 6.9%. Prices had risen from just under 0.40 €/MWh in 2020 to approximately 1.51 €/MWh by the end of the observation.

5.2 Scenario 2: Sustainable Development

Compared to the first scenario, and in line with IEA's sustainable development scenario, the second one assumes a more sustainable development of industry and household demands, and the production of electricity from RES is assumed to be greater than in the status quo.

With the same issue rates as in the first scenario, but with increased RES production, GoO volumes were expected to exceed status quo volumes. A steady increase of GoO volumes in the EECS was observed. While GoO volumes in 2020 are comparable to those of the first scenario, with 631.67 TWh and 621 TWh, respectively, the amount of issued GoOs in 2040 greatly exceeded the values obtained in the first scenario, as a total of 2246.9 TWh were issued in the model's estimation. Compared to Scenario 1, the distribution of issued GoOs amongst different types remained roughly the same, with French hydro, French wind, Italian hydro, Norwegian hydro, and Spanish wind having the highest volumes over the observed timeframe.

On average, prices per country increased by only 1.84% per year. In opposition to the first scenario, two countries had negative growth rates: while Serbia experienced a yearly decline of price levels of 4.3%, GoOs from Luxembourg had a CAGR of -0.68%. The highest growth rate was observed for Norwegian GoOs. Prices increased from an initial 0.03 €/MWh to 0.29 €/MWh, marking a nearly ten-fold increase and a CAGR of 12.35%. On average, prices per technology increased by 1.36% per year. However, GoOs of the type Other RES experienced a decline of 0.07% from the beginning of issuance in 2025. Geothermal GoOs once again marked the highest prices with a steady increase from 5.13 €/MWh in 2020 to 6.77 €/MWh in 2040. In this scenario, however, their lead was significantly lower with prices for Solar GoOs averaging 4.43 €/MWh in 2020 and 4.91 €/MWh in 2040.

5.3 Scenario 3: Full Harmonization

The third scenario was characterized by full harmonization of regulations amongst AIB members concerning the issuance of GoOs in the EECS. Here, countries issuing GoOs although the corresponding produced green electricity had received some form of governmental subsidy were given issue rates corresponding to the average issue rates of category 5. With an average CAGR of 7.17%, GoO volumes experienced higher growth rates in this scenario than in the two preceding ones. Another difference that must be noted is that amongst the ten most issued GoO types in 2020 and 2040 alike, nine hydro GoOs were found. In both years, the other technology was wind. Interestingly, for the first time, two German GoO types – hydro and wind – were listed amongst the ten most issued GoOs in 2040. The total amount of GoOs issued per year was significantly lower than in the other scenarios, see Fig. 6.

Similarly to the results obtained in the first scenario, yearly growth rates were positive for ever country apart from Serbia. Here, the CAGR was -3.77%. Lithuania experienced the highest annual growth rate of 6.66%. In the first year, i.e. 2020, GoOs from Cyprus, Serbia, and Belgium fetched the highest prices with 7.36 €/MWh, 5.21 €/MWh and 4.97 €/MWh, respectively. By 2040, Cyprian GoOs had reached prices of 8.98 €/MWh. Dutch and Irish price levels had exceeded Serbian and Belgian prices by fetching 7.89 €/MWh and 7.03 €/MWh, respectively. Norwegian prices remained low: starting from 0.25 €/MWh in 2020, by 2040, they had merely reached a level of 0.68 €/MWh. For comparison, the next lowest average price, which corresponded to Swedish GoOs, reached a level of 1.92 €/MWh. In the beginning of this scenario's observation, solar GoOs achieved the highest price levels: in 2020, prices were found to lie at 12.19 €/MWh. After a minor increase and a sharp drop to 8.33 €/MWh in 2025, prices reach their highest level of 12.57 €/MWh in 2040 where they were exceeded by geothermal GoOs that reached 12.82 €/MWh. In every observed year, hydro GoOs had the lowest prices.

5.4 Scenario 4: Ideal Scenario

The fourth scenario combined assumptions made in Scenarios 2 and 3. While the development of supply, i.e. green electricity production, and demand were determined by the assumptions made in Scenario 2, GoO issue rates corresponded to those estimated in Scenario 3. Therefore, this final analysis represented a green transition with full harmonization amongst AIB members.

In the first observed period, 2020, GoO volumes were comparable to those found in Scenario 3. However, by 2040, volumes exceeded those of the first scenario. In this year, more than 1684.89 TWh were issued. This resulted in an extraordinary annual growth rate of 8.85%. The distribution of GoO types is equivalent to that of Scenario 3, with hydro GoOs being the dominant type. Throughout the whole observation, nine out of the ten most issued GoO types were hydro GoOs.

In this scenario, eleven countries experienced negative annual growth rates for GoO prices when the WAVG was analyzed. Serbia, Belgium, and Croatia experienced the strongest decline with rates of -6.46%, -2.11% and -2.04%, respectively. The steepest increase was once again found for Lithuania with a CAGR of 3.48%. In 2020, Cyprus, Belgium, and Serbia achieved the highest price levels. In 2040, Cyprus remained at the top with an average price of 6.28 €/MWh, followed by Ireland and the Netherlands, that fetched prices of 4.89 €/MWh and 4.08 €/MWh, respectively.

The negative price trends observed in the average prices per country could also be found when averaging prices per technology. Apart from geothermal GoOs that had an average CAGR of 4.89%, all technologies experienced a decline in average price levels. Solar GoOs had the lowest annual growth rate at -2.93%. In 2020, solar GoOs fetched the highest average prices of 12.19 €/MWh. This declines to 6.72 €/MWh in 2040. By then, geothermal GoOs had become the most expensive type at 11.91 €/MWh

5.5 Scenario Comparison

After presenting the results of the four analyzed scenarios individually, they will now be brought into context by comparing certain results with one another.

When directly comparing the amount of GoOs issued amongst the different scenarios, as shown in Figure 5, it can be seen that these volumes vary greatly between the scenarios. The highest GoO volumes were found in Scenario 2. This makes sense, as this scenario assumed an increased production of green electricity, compared to Scenarios 1 and 3, and had no further regulations concerning the limitation of GoO issuance for subsidized electricity in place. This means that countries that had high issue rates in the first scenario issued more GoOs because their electricity production from RES increased. The development of Scenario 3 was quite the opposite. Here, green electricity generation was at the same level as the status quo, but regulations concerning the issuance of GoOs for subsidized electricity were in place, a harmonization amongst AIB member was conducted. This resulted in a reduction of the supply of GoOs, as countries would produce the same amount of green electricity as in Scenario 1, but issue rates would be substantially lower than before. Scenario 4 combined assumptions of Scenarios 2 and 3. Initial GoO volumes were at a similar level as in Scenario 3 but increased rapidly to exceed volumes seen in Scenario 1 by the end of the observed timeframe. This is supported by the average CAGR for Scenario 4 that, with a value of 8.85%, was the highest growth rate amongst all scenarios. In all scenarios, hydro GoOs were the most abundant, followed by wind.

To make prices comparable, the WAVG was calculated over all technologies and countries per scenario. Over all four scenarios, the price corridor ranged from 1.22 to 1.61 €/MWh in 2020 and 1.77 to 3.36 €/MWh in 2040. This resulted in the price developments shown in Fig. 7. Here, it can be seen that, on average, GoO prices in Scenario 3 were the highest throughout the complete regarded timeframe. In this model, prices are determined mainly by the relation of demand and supply. Therefore, it makes sense for the highest prices to have been observed in the scenario with the lowest supply, i.e. Scenario 3, see Fig. 6. Consequently, the lowest prices were found in the scenario with the highest supply, namely Scenario 2. As the initial supply, in 2020, in Scenario 4 was lower than in Scenario 1, it was no surprise for average prices in Scenario 4 to be slightly higher than in the status quo. With supply having increased over the years, a fall in prices was to be expected.

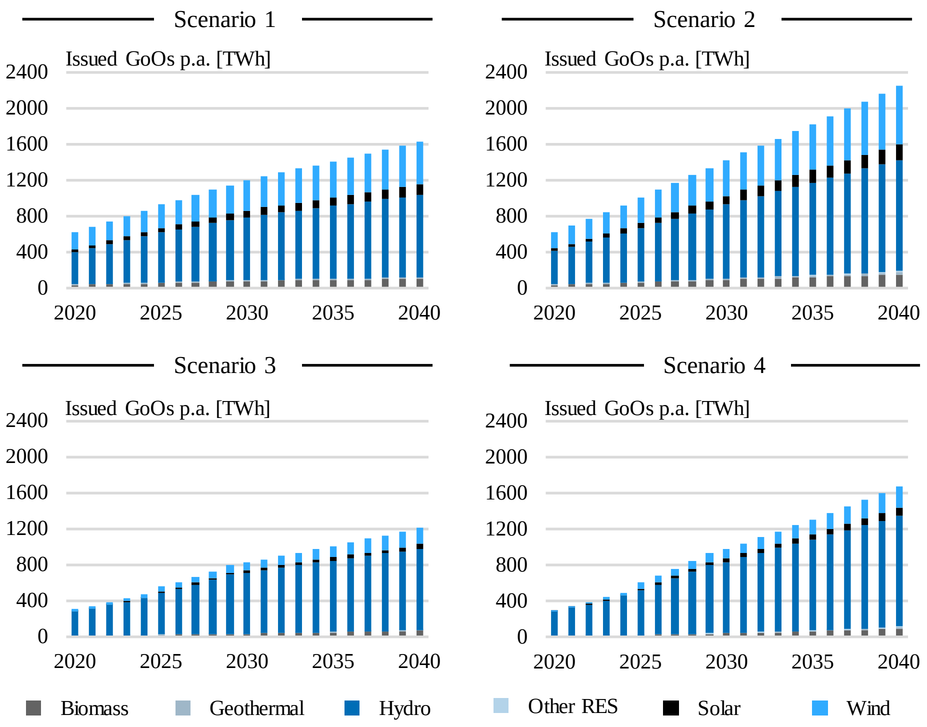

Fig. 6. Comparison of issued GoO volumes for all four scenarios

Abbreviation used: GoO = Guarantee of Origin; RES = Renewable energy sources

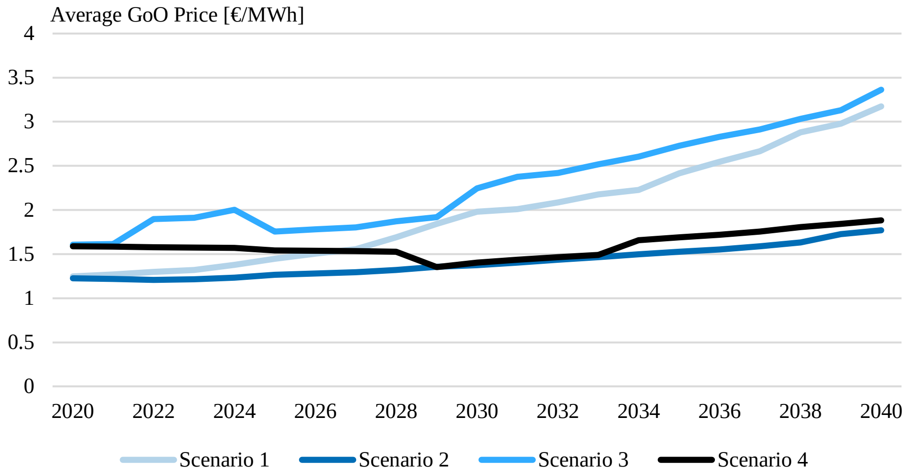

Fig. 7. Development of average prices over all technologies and all countries for GoOs per scenario

Abbreviation used: GoO = Guarantee of Origin

When comparing average prices for the different technologies, the same pattern arose amongst all four scenarios. While in Scenarios 3 and 4, in the beginning, geothermal GoO prices were lower than other prices were, they finally surpassed all other technologies and continuously fetched the highest prices from 2025 to 2040. For all scenarios, the next highest prices in descending order were solar, other RES, wind, biomass, and finally hydro. In Scenario 3, however, prices for geothermal and solar GoOs in 2040 were close, with average prices of 12.82

and 12.57 €/MWh, respectively. The development of these prices for each scenario isdepicted in Fig. 8. Additionally, Table 4 provides an overview of prices per technology for each scenario for the years 2020, 2030 and 2040.

When closely examining Fig. 8, it can be noticed that around 2025, GoOs of the type “other RES”, and in Scenarios 3 and 4, also those of the types “geothermal” and “solar”, experience sudden jumps in price levels. For GoOs of the type “other RES”, this is easily explained, as the issuance of this type only begins in 2025. The drop of solar GoOs in the last two Scenarios can be explained by the increase of supply that occurs in 2025. In these scenarios, issue rates, and thus GoOs on the market, are limited by assumed harmonization measures amongst AIB members. In 2025, when countries begin issuing GoOs for technologies that had previously not received any GoOs, supply increases and, as the market is demand-driven, prices are reduced. However, for geothermal GoOs, the opposite price development occurs. Here, when supply increases in 2025, prices also increase. This is caused by the sudden appearance of more desired geothermal GoOs on the market. From 2020 to 2024, the only geothermal GoOs on the market that are available in sufficiently high quantities to set prices, are from Iceland. The WTP for Icelandic GoOs is low compared to other countries because of the geographical derating factors that were applied to the WTP values, see Table A-5. Consequently, when geothermal GoOs from other countries, such as Portugal, enter the market, the overall price will increase because consumers have higher WTPs for these GoOs. Additionally, it must be said that in reality, these jumps would probably not occur. Instead, the price increases or decreases would likely follow a less steep curve as technology portfolio diversification and increased GoO issuance would happen gradually.

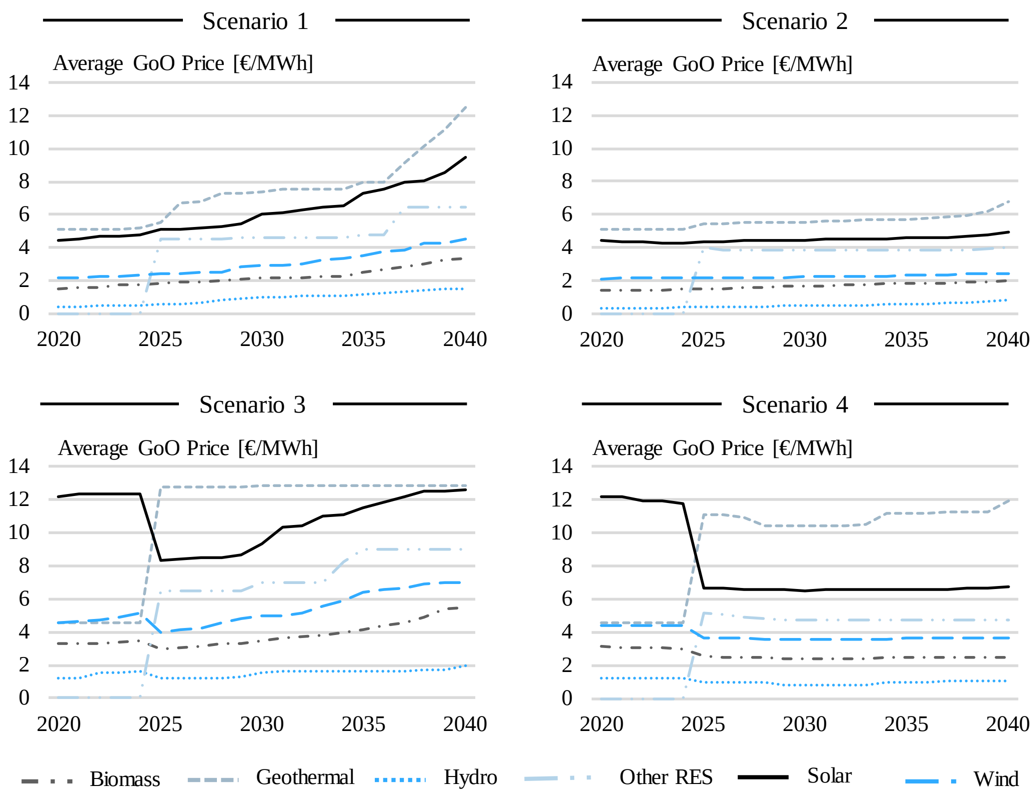

Fig. 8. Comparison of price developments per technology for all four scenarios

Abbreviation: GoO = Guarantee of Origin; RES = Renewable energy sources

Table 4. Average GoO prices in €/MWh per technology for all four scenarios, in the years 2020, 2030, and 2040

	Scenario 1			Scenario 2		
Technology	2020	2030	2040	2020	2030	2040
Biomass	1.47	2.12	3.36	1.44	1.67	1.98
Geothermal	5.13	7.33	12.54	5.13	5.56	6.77
Hydro	0.4	0.99	1.51	0.37	0.47	0.82
Other RES	0	4.59	6.45	0	3.86	3.98
Solar	4.46	6.03	9.5	4.43	4.46	4.91
Wind	2.15	2.88	4.47	2.14	2.22	2.47
	Scenario 3			Scenario 4		
Technology	2020	2030	2040	2020	2030	2040
Biomass	3.26	3.46	5.51	3.13	2.41	2.49
Geothermal	4.59	12.8	12.82	4.59	10.41	11.91
Hydro	1.23	1.55	1.93	1.23	0.8	1.06
Other RES	0	7	8.97	0	4.73	4.77
Solar	12.19	9.3	12.57	12.19	6.53	6.72
Wind	4.59	4.96	7	4.44	3.54	3.66

Abbreviations used: GoO = Guarantee of Origin; RES = Renewable energy source

When looking at the technologies achieving the highest price levels, it was stated that, on average, over all scenarios, geothermal GoOs were the most expensive. This finding, however, varies when looking at different countries in the scenarios. In those scenarios that underlined an increase in green electricity production by adding previously unused technologies, such as geothermal for most countries, to their technology portfolio, i.e. Scenarios 2 and 4, the highest prices were ultimately determined by geothermal GoOs, as the WTP for these was the highest and a scarcity of such GoOs existed in all countries. In the appendix of this paper, all prices are given per scenario, country, and technology. Thus, in this section, only a few notable examples will be given. For example, in the first scenario, solar GoOs were the most expensive GoOs in Belgium, Denmark, Switzerland, Spain, and the Czech Republic, amongst others. In other countries, e.g. Ireland, wind was the most expensive technology over the complete timeframe. Changes in which technology was the most expensive in a respective country occurred in ten countries. For example, in Germany, prices for geothermal GoOs exceed those of solar GoOs in 2025. In 2025, GoOs of the type Slovenian solar became more expensive than their counterparts that were generated from hydropower. In Scenario 3, nine countries experienced a change in the most expensive technology. Here, in most countries, solar GoOs fetched the highest prices. By 2040, only six countries had geothermal GoOs achieving higher price levels, and only four countries were experiencing high wind prices that exceeded solar GoO prices.

When minimum prices were regarded, a similar pattern to that in the prior maximum price analysis arose. In general, one technology was dominant: for all four scenarios, hydro GoOs fetched the lowest prices in most countries. As was shown in Subsection 3.1.1, hydro GoOs are currently by far the most abundant type of GoO in the EECS. Therefore, when keeping the model's design in mind, these results were to be expected. Only a few exceptions occurred. The most notable in each scenario was Cyprus, where the lowest prices were fetched by wind GoOs up until 2025. Then, in Scenarios 1 and 3, biomass became the cheapest technology. In Scenarios 2 and 4, from 2025 onwards, hydro GoOs were even cheaper. In Serbia, the cheapest prices were produced by biomass. But here, also from 2025 onwards, hydropower became cheaper.

One of the assumptions of the model was that no lower price boundary exists. This becomes important when regarding prices for Norwegian hydro in Scenarios 1 and 2. Here, up until 2022 and 2027, respectively, prices of 0 €/MWh were calculated. This resulted from the still occurring over-supply of GoOs in these two scenarios. With Norwegian hydro being one of the most abundant types of GoO and consumers having the lowest WTP, it is no surprise that these prices are so low. In Scenario 2, where the highest amounts of GoOs were issued, the same occurred for Swedish hydro up until 2023.

6. Discussion

In this section, we discuss the obtained results by comparing the achieved prices with estimations from market participants taken from two independent surveys. Additionally, the model's limitations and the resulting implications for the development of prices are critically analyzed.

6.1 Validation of Results

To validate the obtained results, two surveys were obtained, that had asked participants to estimate the development of future GoO prices. In the results of the first survey, conducted by Greenfact (2020, pp.16-17)Klicken oder tippen Sie hier, um Text einzugeben., expected prices for 2021 were between 0.2 and 0.3 €/MWh for hydro and between 0.3 and 0.4 €/MWh for wind GoOs. In the other survey, participants were asked to state their price expectations for German GoOs, independently of the respective technology. For 2025, the average price was expected to be approximately 1.6 €/MWh. Prices were expected to increase to just over 2 €/MWh by 2030 (Köpke, 2020, p.16).

As stated earlier, the European GoO market is characterized by high uncertainty, speculative behavior of the participants, and a lack of transparency, and thus insight, because most trades occur bilaterally (over-the-counter). Therefore, the answers from the just presented surveys are not guaranteed to be correct, especially when keeping in mind the volatile situation regarding possible European regulations on carbon-neutrality. Nevertheless, as they were conducted amongst market participants and experts, they do give some indication as to whether the model's results are sufficiently realistic.

When examining prices for wind GoOs in 2021, it can be seen that the results obtained in the scenarios greatly exceeded the estimations expressed in the first survey. In Scenarios 1 and 2, average prices for wind GoOs were expected to lie at 2.19 and 2.14 €/MWh, respectively. In Scenarios 3 and 4, price levels practically doubled. Here, they reached levels of 4.64 and 4.43 €/MWh, respectively. The lowest prices for wind GoOs, and thus closest to the given estimation in the survey, were those calculated for GoOs from Norway in Scenario 1. These prices were estimated at 0.97 €/MWh in 2021. However, these prices still exceeded the price estimations of the market participants by more than 100%.

On average, hydro prices lay closer to the estimate than wind prices did. In Scenarios 1 and 2, prices for GoOs for green electricity from hydropower in 2021 were calculated as 0.41 and 0.37

€/MWh, respectively. This is very close to the average price from the first survey. In both scenarios, prices for hydro GoOs in Norway and Sweden reached zero. This means that the demand for these two GoO types exceeded the supply. In reality, these prices would have probably ranged at the current price levels of about 0.2 €/MWh because this oversupply reflected the current situation in the EECS. In the other two scenarios, average hydro prices were expected to reach 1.23 and 1.22 €/MWh, respectively. Due to these scenarios' assumptions regarding the harmonization of regulations, and the resulting reduction of GoO issue rates amongst AIB member states, a situation of oversupply did not occur for any type of GoO. However, once again, prices for Norwegian Hydro GoOs were the closest to the survey's estimation. These prices were calculated to 0.24 €/MWh in 2021. Swedish GoOs were the next lowest at 0.6 €/MWh.

In general, in the model's results, prices for GoOs from Germany were slightly below the European average. As can be seen in Table 5, prices calculated in the first scenario were closest to the survey's results. In Scenario 2, the supply of GoOs was raised by an increased production of green electricity and the diversification of technology portfolios in all countries. Consequently, prices were lower. The opposite occurred in Scenarios 3 and 4. Here, prices were far higher and exceeded by far the survey's results in 2025 and 2030. This was caused by the limitation of the supply of GoOs in the EECS.

Table 5. GoO prices in Germany obtained from a survey amongst market participants compared to the results obtained from the model's calculation [€/MWh]

Observed year	2025	2030
Survey	1.6	2.02
Scenario 1	1.03	1.73
Scenario 2	0.81	0.83
Scenario 3	3.32	3.8
Scenario 4	3.18	3.17

Source: Köpke (2020), own calculations

An additional validation tool is the comparison of the model's results with historic prices. Prices ranging up to 8 €/MWh for certain types of GoOs, in this case Dutch GoOs, have been seen in the past. Additionally, when demand was high enough, a situation which has in the past been artificially stimulated through speculative behavior on the market, prices were seen to greatly exceed current levels and to even surpass average prices calculated in the model presented here. When regarding prices paid for GoOs issued by new power plants, i.e. those that are not older than six years, a similar observation can be made, as these prices were found to reach levels of up to 3.4 €/MWh. Swiss GoOs even fetched prices ranging up to 4 €/MWh, which is higher than any average result for this type in any scenario of our study (see historic prices in Table 4 for further comparison).

Therefore, following the analysis of this section, we find that the prices obtained by this model's calculation are, in general, in the range of previously seen prices. For some scenarios and certain GoO types, prices resemble the estimations made by market participants and experts. Some anomalies occurred, such as high prices for geothermal GoOs or for solar GoOs (in Scenarios 3 and 4). However, while the first example cannot be easily explained or falsified due to a lack of historic price information on geothermal GoOs, the latter can be explained by the scenarios' drastic reduction of supply and consequential creation of higher prices through the limitation of GoO issue rates and increased harmonization amongst AIB member states.

A sensitivity analysis showed the model's dependence on different input variables. The results are shown in Fig. 9. Six variations were conducted for each selected parameter or variable. The first three reduced the selected parameters' values by factors of 0.1, 0.2, and 0.5, respectively. The other three calculations increased the same values by factors of 2, 5, and 10. It can be seen that the variable "WTP percentages" had the highest influence on GoO prices, while the LCOE cap had almost no influence. This gives an indication of the model's assumptions. The logarithmic scale was chosen to adequately show the price variations (since no negative values occurred, this was applicable).

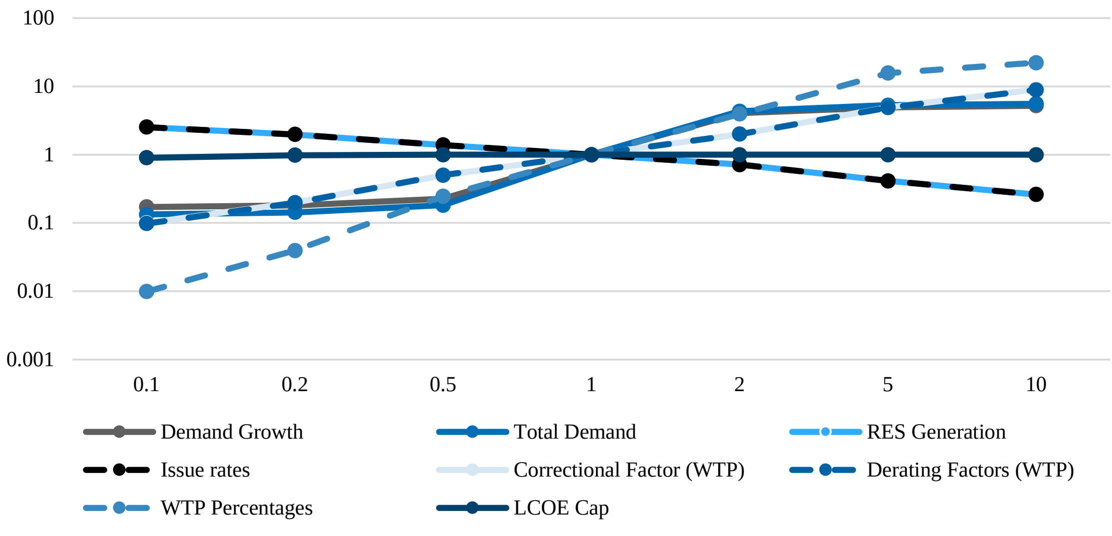

Fig. 9. Sensitivity analysis

Abbreviations used: RES = Renewable energy sources; WTP = Willingness-To-Pay; LCOE = Levelized Cost of Electricity

7. Conclusions and Policy Implications

The aim of this study was twofold. The first goal was to provide some insights into the European GoO market. This was achieved by analyzing individual member countries' activities in terms of issuance, trade, and cancelation of GoOs and by classifying these countries into different categories. Additionally, the past and the possible future development of the market and resulting prices were scrutinized. This analysis revealed a lack of harmonization in the GoO market and stressed its volatile behavior. They also provided a basis for the second aim, namely to design a model that would be able to forecast GoO prices based on historic statistical facts and key assumptions and scenarios. On the basis of extended analyses of European energy demand and supply, structural statistics, as well as publicly available GoO data, the model was able to provide insight into possible future price developments of GoOs of different technologies and origins on a yearly basis up until 2040. When examining the prices that were obtained from the model's calculations, it was found that most GoO types reached levels that had previously occurred in the market. Comparing these prices to expert expectations from surveys, it was found that these results were somewhat realistic when taking the uncertainty of the used data and the mentioned unpredictable market behavior into account.

Although GoOs were originally introduced in order to disclose the production of green electricity to European consumers – a purpose that they generally fulfil – the public opinion of this system is negative, as GoOs currently provide little or no incentive to increase the production of green electricity. As stated earlier, in order for GoOs to become relevant in green electricity producers' investment decisions, prices must increase to above levels of current governmental support schemes and subsidies for RES. For wind, these prices range between 15 to 25 €/MWh, for solar from 17 to 22 €/MWh, and for biomass up to 89 €/MWh (Dagoumas & Koltsaklis, 2017, p.64). However, even in Scenario 3, where full harmonization amongst participating AIB member states is assumed – and thus a substantial reduction of the supply of GoOs on the market – prices were on average far off these targets, with geothermal and solar GoOs achieving average prices of just over 12.5 €/MWh in 2050.

Therefore, we can conclude that GoOs are not likely to become a dedicated policy category for the promotion of green electricity production in Europe. If policy makers, however, were to further increase harmonization amongst issuing AIB member states, as is currently being done in the earlier mentioned *FaStGO* project (AIB 2019b), GoOs could lose their negative image, and the often stated arguments of double counting and greenwashing could be refuted (AIB, 2019b). Additionally, if prices for GoOs increased as forecast by the model, consumers willing to purchase green electricity at low costs might switch to other alternatives for green power acquisition, such as PPAs, that have a more direct impact on the increase of green electricity production.

Finally, it can be said that in the wake of European efforts to decarbonize the economy and to significantly increase the amount of RES in electricity production, the GoO market volume will increase in the coming years. With both household and corporate consumers becoming more aware of the necessity to purchase green electricity, demand will increase and drive GoO prices to higher levels. With current policies and the actual state of harmonization in the market, however, the GoO system will not be able to overcome the trust issues that it is currently experiencing. Additionally, prices will remain at levels that will have only marginal effects on the increase of green electricity production. Therefore, harmonization amongst AIB member states concerning the issuance of GoOs, the provision of GoO data without discrepancies, the promotion of the GoO system as a provider of viable and trustworthy disclosure, and the creation of a possible further RES production incentive system based on GoOs must become higher priorities of European policy makers. These steps would allow the GoO system to become a market-driven incentive model and would free up governmental funds that could be invested in other projects concerning the decarbonization of European economies.

With green electricity and decarbonization becoming more and more important in public discussions and being prioritized topics of European legislature, the significance of these topics is set to increase in the upcoming years. Therefore, future research should focus on reducing the limitations of our proposed model and increasing its accuracy. For example, by analyzing GoO data on a monthly basis, seasonal factors in the production of green electricity could be included and thus provide a more accurate depiction of the real market situation. A major factor of uncertainty was the determination of the WTP for green electricity – and thus GoOs for industrial consumers. A survey-based determination of this WTP would not only improve future GoO price models' results, but could also be applied to other research focusing on alternative acquisition possibilities for green electricity, and thus providing valuable new insights potentially useful in various research focusing on the promotion of RES in electricity production.

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Appendix

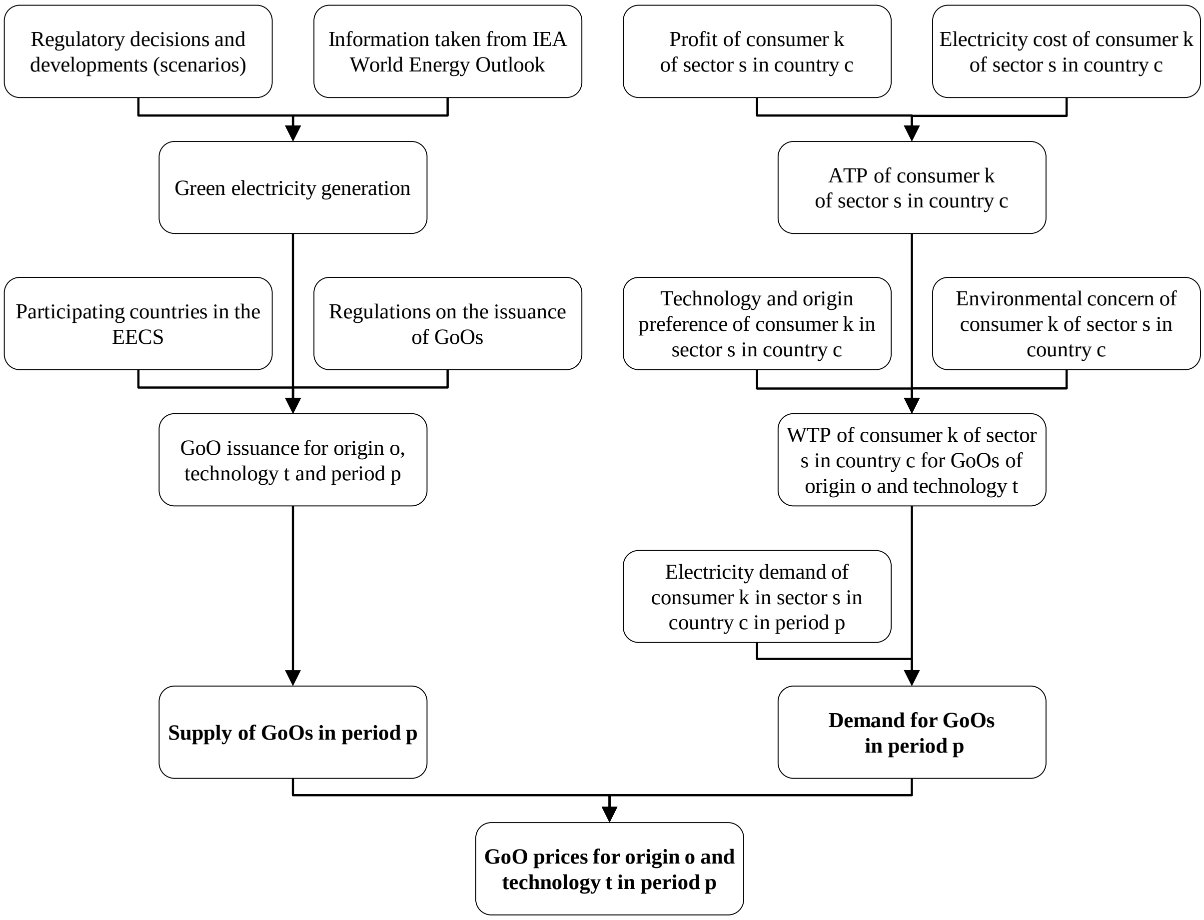

Fig. A-1: Data flow diagram

Table A-1: Overview of historic prices

Type of GoO	Period	Price / price range	Source
Alpine Hydro Power	2017	0.2 €/MWh	Dagoumas & Koltaklis (2017): P. 65
Austrian (Unspecified)	2018	0.9 – 1.45 €/MWh	Hauser et al. (2019): P. 214
Austrian Hydro (Age unspecified)	2019	1.32 €/MWh	Advantag Services GmbH (10.09.2020)
Dutch Wind	September 2018	8 €/MWh	Münster (06.08.2020)
EU Biomass (Unspecified)	2018	1.62 €/MWh	Advantag Services GmbH (10.09.2020)
EU Hydro (Age unspecified)	2018	1.24 – 1.25 €/MWh	Hauser et al. (2019): P. 214, taken from Nvalue in 2018
EU Hydro (Unspecified)	2020	0.15 – 0.21 €/MWh	Nvalue AG (02.09.2020)
EU Hydro (Unspecified)	2018-2020	0.49 - 1.98 €/MWh	Advantag Services GmbH (10.09.2020)
German (Unspecified)	2018	0.8 – 1.6 €/MWh	Hauser et al. (2019): P. 214
Large Nordic Hydro	2007-2015	0.05 – 0.6 €/MWh	Oslo Economics (2018): P. 21
Nordic (Unspecified), new	2018	2 – 2.7 €/MWh	Hauser et al. (2019): P. 214
Nordic (Unspecified), new	2018	2.34 – 3.4 €/MWh	Hauser et al. (2019): P. 215
Nordic (Unspecified), old	2018	0.55 €/MWh	Hauser et al. (2019): P. 214
Nordic (Unspecified), retrofitted	2018	1 – 1.9 €/MWh	Hauser et al. (2019): P. 215
Nordic Hydro (Age unspecified)	2015	0.05 – 0.5 €/MWh	Klimscheffskij et al. (2015): P. 4672
Nordic Hydro (Age unspecified)	2017	0.22 – 0.38 €/MWh	Hauser et al. (2019): P. 213
Nordic Hydro (Age unspecified)	09/2018 – 12/2018	1.24 - 2 €/MWh	Münster (06.08.2020)
Nordic Hydro	2017	0.31 €/MWh	Dagoumas & Koltaklis (2017): P. 65
Northern Continental Europe Wind Power	2017	0.45 €/MWh	Dagoumas & Koltaklis (2017): P. 65
Swiss (Unspecified)	2018	1.5 – 4 €/MWh	Hauser et al. (2019): P. 214
Swiss Hydro	2017 - 2018	1 – 4 CHF/MWh	Münster (06.08.2020)
Swiss PV (Unspecified)	2018	14.30 €/MWh	Advantag Services GmbH (10.09.2020)

Abbreviations and explanations: EU = European in general; GoO = Guarantee of Origin; *Hydro* refers to GoOs from hydropower generation; *Nordic* refers to GoOs from Denmark, Finland, Norway, or Sweden; *PV* refers to GoOs from solar (photovoltaic) generation

Table A-2. Overview of household WTPs

	WTPs for green electricity				
	0%	> 0%	> 25%	> 50%	> 75%
France	28.5	56	10.5	4.5	0.5
Netherlands	32	56	8.5	3	0.5
Spain	28	56	11	4	1
Sweden	23	62	10	4	1
Switzerland	8.5	72	15	4	0.5
EU Average	24	60.4	11	3.9	0.7
Reduced WTP for GoOs (% of total electr. price)	0	0.0375	0.1125	0.1875	0.24

Abbreviations used: GoO = Guarantee of Origin; WTP = Willingness-to-pay

Source: OECD (2014): pp.102-103, own estimation

Table A-3. Values for *environmental concern* for WTP calculation

Sector Description	NACE Code	Environmental concern	Source
Sewerage	E37	0.5	RE100 (20.10.2020)
Architectural and engineering activities; technical testing and analysis	M71	0.45	RE100 (20.10.2020)
Accommodation	I55	0.5	RE100 (20.10.2020)
Remediation activities and other waste management services	E39	0.6	RE100 (20.10.2020)
Retail trade, except for motor vehicles and motorcycles	G47	0.7	RE100 (20.10.2020)
Computer programming, consultancy, and related activities	J62	0.8	RE100 (20.10.2020)
Mining support service activities	B09	0.2	Own estimation
Office administrative, office support, and other business support activities	N82	0.6	Own estimation
Mining of metal ores	B07	0.2	Own estimation
Scientific research and development	M72	0.65	Own estimation
Food and beverage service activities	I56	0.5	Own estimation
Services to buildings and landscape activities	N81	0.6	Own estimation
Manufacture of beverages	C11	0.75	RE100 (20.10.2020)
Extraction of crude petroleum and natural gas	B06	0.1	Own estimation
Other mining and quarrying	B08	0.15	Own estimation
Wholesale trade, except for motor vehicles and motorcycles	G46	0.6	RE100 (20.10.2020)
Wholesale and retail trade and repair of motor vehicles and motorcycles	G45	0.4	Own estimation
Manufacture of wearing apparel	C14	0.55	Own estimation
Manufacture of chemicals and chemical products	C20	0.5	RE100 (20.10.2020)
Manufacture of computer, electronic, and optical products	C26	0.3	RE100 (20.10.2020)
Printing and reproduction of recorded media	C18	0.4	Own estimation
Manufacture of electrical equipment	C27	0.4	Own estimation
Manufacture of other non-metallic mineral products	C23	0.35	Own estimation
Manufacture of rubber and plastic products	C22	0.3	Own estimation
Manufacture of wood and of products of wood and cork, except for furniture; manufacture of articles of straw and plaiting materials	C16	0.65	Own estimation
Manufacture of motor vehicles, trailers, and semi-trailers	C29	0.45	RE100 (20.10.2020)
Manufacture of leather and related products	C15	0.6	Own estimation
Manufacture of fabricated metal products, except for machinery and equipment	C25	0.5	Own estimation
Manufacture of furniture	C31	0.7	Own estimation
Manufacture of food products	C10	0.65	RE100 (20.10.2020)
Manufacture of paper and paper products	C17	0.4	RE100 (20.10.2020)
Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21	0.4	RE100 (20.10.2020)
Other manufacturing	C32	0.5	Own estimation
Manufacture of textiles	C13	0.7	RE100 (20.10.2020)
Motion picture, video and television program production, sound recording, and music publishing activities	J59	0.6	Own estimation
Information service activities	J63	0.75	RE100 (20.10.2020)
Mining of coal and lignite	B05	0.1	Own estimation

Sector Description	NACE Code	Environmental concern	Source
Manufacture of coke and refined petroleum products	C19	0.1	Own estimation
Manufacture of machinery and equipment n.e.c.	C28	0.4	RE100 (20.10.2020)
Manufacture of basic metals	C24	0.4	Own estimation
Legal and accounting activities	M69	0.3	RE100 (20.10.2020)
Travel agency, tour operator, and other reservation service and related activities	N79	0.5	Own estimation
Repair and installation of machinery and equipment	C33	0.4	Own estimation
Repair of computers and personal and household goods	S95	0.4	Own estimation
Programming and broadcasting activities	J60	0.4	Own estimation
Waste collection, treatment, and disposal activities; materials recovery	E38	0.7	Own estimation
Other professional, scientific, and technical activities	M74	0.6	Own estimation
Manufacture of other transport equipment	C30	0.35	Own estimation
Manufacture of tobacco products	C12	0.4	Own estimation
Telecommunications	J61	0.8	RE100 (20.10.2020)
Publishing activities	J58	0.5	Own estimation
Rental and leasing activities	N77	0.6	Own estimation
Employment activities	N78	0.4	Own estimation
Activities of head offices; management consultancy activities	M70	0.65	RE100 (20.10.2020)
Veterinary activities	M75	0.4	Own estimation
Security and investigation activities	N80	0.2	Own estimation
Water collection, treatment, and supply	E36	0.7	Own estimation
Advertising and market research	M73	0.8	RE100 (20.10.2020)

Abbreviations used: NACE = Nomenclature générale des activités économiques dans les Communautés Européenne (Classification of European Economic Statistics)

Source: RE100 (2020.10.2020), own estimations

Table A-4: Overview and categorization of EECS member countries as of mid-2019

Country (Or Country area)	Competent body	Subsidy category	Fees	National certificate system	International trade	Own domestic platform
Austria	E-Control	Cat. 1	No	No	Yes	Yes
Belgium (Federal)	CREG	Cat. 4	No	No	Yes	Yes
Belgium Brussels	Brugel	Cat. 4	No	No	Yes	Yes
Belgium Flanders	VREG	Cat. 4	Yes	Yes	Yes	Yes
Belgium Wallonia	SPW Energie / CWaPE	Cat. 4	No	Yes	Yes	Yes
Switzerland	Pronovo	Cat. 1	Yes	No	Yes	Yes
Cyprus	TSOC	Cat. 3	Yes	Yes	Yes	Yes
Czech Republic	OTE	Cat. 4	Yes	No	Yes	Yes
Germany	UBA	Cat. 5	Yes	Yes	Yes	Yes
Denmark	Energinet	Cat. 1	Yes	No	Yes	No (CMO.grexel)
Estonia	Elering	Cat. 1	Yes	No	Yes	Yes
Spain	CNMC	Cat. 4	No	Yes	Separation of GoOs intended for import and export	Yes
Finland	Finextra	Cat. 1	Yes	Yes	Yes	Yes
France	EEX	Cat. 2	Yes	No	Yes	Yes
Greece	DAPEEP / HEDNO / CRES	Cat. 4	No	Yes	Yes	Yes
Croatia	HROTE	Cat. 4	Yes	No	Yes	No (CMO.grexel)
Ireland	SEMO	Cat. 5	No	No	Yes	No (CMO.grexel)
Iceland	Landsnet	Cat. 6	Yes	No	Yes	No (CMO.grexel)
Italy	GSE	Cat. 1	Yes	No	Yes	Yes
Lithuania	Litgrid AB	Cat. 3	Yes	Yes	Only import	No (CMO.grexel)
Luxembourg	ILR	Cat. 2	Yes	No	Yes	No (CMO.grexel)
Netherlands	CertiQ	Cat. 4	Yes	No	Yes	Yes
Norway	Statnett	Cat. 4	Yes	No	Yes	Yes
Portugal	Rede Eléctrica Nacional, S.A. (REN)	Cat. 1	Yes	Yes	Yes	Yes
Serbia	EMS	Cat. 5	Yes	No	Yes	Yes
Sweden	Energimyndigheten	Cat. 4	Yes	Yes	Yes	Yes
Slovenia	Energy Agency / Borzen	Cat. 2	Yes	Yes	Yes	Yes
Slovakia	OKTE	Cat. 2	Yes	No	Yes	Yes

Country (Or Country area)	Trade balance (2015-2019)	Trade hub (2015-2019)	Consumption (2015-2019)	Proportion of issuance (2019)	Proportion of cancel. (2019)	Shifted prop. of cancel. (2019)
Austria	Negative	Yes	Consumer	0.021424047	0.037883179	0.032454632
Belgium (Federal)	Negative	Yes	Consumer	0.016463224	0.039611106	0.035522748
Belgium Brussels	Lack of data	Lack of data	Lack of data	0	0	0
Belgium Flanders	Lack of data	Lack of data	Lack of data	0	0	0
Belgium Wallonia	Lack of data	Lack of data	Lack of data	0	0	0
Switzerland	Negative	No	Consumer	0.095128656	0.088430042	0.083808439
Cyprus	Lack of data	Lack of data	Producer	0.000337672	0	0
Czech Republic	Positive	No	Producer	0.008335271	0.000983337	0.001864038
Germany	Negative	No	Consumer	0.022031789	0.173304752	0.158670194
Denmark	Positive	No	Producer	0.028931447	0.014841155	0.013331771
Estonia	Positive	Yes	Producer	0.004086356	0.000471532	0.000578586
Spain	Positive	No	Producer	0.143756032	0.125417968	0.120358496
Finland	Positive	No	Producer	0.040907033	0.04149955	0.037288875
France	Positive	No	Producer	0.079916686	0.067765929	0.075425313
Greece	Lack of data	Lack of data	Lack of data	0	0	0
Croatia	Positive	No	Producer	0.007435576	0.002644953	0.003194225
Ireland	Negative	No	Consumer	0.003198566	0.011490545	0.011640314
Iceland	Positive	No	Producer	0.023687093	0.006319384	0.004605022
Italy	Positive	No	Producer	0.129264574	0.077423193	0.080583479
Lithuania	Negative	No	Consumer	0.000415937	0.002066573	0.002100529

Luxembourg	Negative	Yes	Consumer	0.000665903	0.005062893	0.006328675
Netherlands	Negative	No	Consumer	0.081629158	0.087323332	0.092680187
Norway	Positive	Yes	Producer	0.188048895	0.109938713	0.105441595
Portugal	Negative	Yes	Consumer	0	0	0
Serbia	Lack of data	Lack of data	Producer	9.94E-06	1.10E-05	6.34E-05
Sweden	Negative	No	Producer	0.099308569	0.106162988	0.09557441
Slovenia	Positive	No	Producer	0.005017581	0.001347882	0.001196152
Slovakia	Lack of data	Lack of data	Lack of data	0	0	0

Note: Belgium (Federal) refers to Belgian offshore territories in the North Sea & English Channel.

Sources: Own calculations based on Agencija za energijo, 2017; AIB, 2020a, 2020b; BRUGEL, 2013; CertiQ B.V., 2018; Comisión Nacional de los Mercados y la Competencia, 2017; Commissie voor de Regulering van de Elektriciteit en het Gas, 2018; Commission wallone pour l'Energie, 2017; DAPEEP S.A., 2013; E-Control, 2019; Elektromreža Srbije JSC Belgrade, 2019; Elering AS, 2015; Energienet.dk, 2016; Energimyndigheten, 2019; Finextra Oy, 2017; Gestore dei Servizi Energetici, 2015; HRVATSKI OPERATOR TRŽIŠTA ENERGIJE, 2016; Institut Luxembourgeois de Régulation, 2018; Landsnet hf., 2015; LITGRID AB, 2018; OKTE, 2019; Operator trhu s elektrinou, a.s, 2018; Powernext SAS, 2019; Pronovo Ltd., 2018; Rede Eléctrica Nacional, S. A, 2020; Single Electricity Market Operator, 2019; Statnett SF, 2018; Transmission System Operator, 2012; Vlaamse Regulator van de Elektriciteits- en Gasmarkt, 2017)

Table A-5: Derating factors applied to WTPs depending on the country of origin

	AT	BE	DK	FI	FR	DE	UK	IT	IE	NL	NO	PO	ES	SW	CH	HR	CY	CZ	ET	GR	IC	LI	LU	SE	SK	SL
AT	1	0.7	0.6	0.6	0.7	0.9	0.4	0.9	0.2	0.6	0.2	0.4	0.4	0.6	0.9	0.7	0.4	0.9	0.7	0.6	0.3	0.4	0.5	0.6	0.9	0.9
BE	0.7	1	0.8	0.7	0.9	0.9	0.7	0.5	0.5	0.9	0.3	0.5	0.5	0.6	0.7	0.5	0.3	0.6	0.5	0.3	0.3	0.5	0.9	0.5	0.6	0.6
DK	0.6	0.8	1	0.8	0.6	0.9	0.6	0.5	0.5	0.7	0.3	0.4	0.4	0.8	0.6	0.4	0.3	0.6	0.7	0.3	0.4	0.7	0.7	0.4	0.5	0.5
FI	0.6	0.7	0.8	1	0.5	0.7	0.5	0.5	0.4	0.7	0.4	0.3	0.4	0.9	0.6	0.4	0.2	0.5	0.9	0.3	0.5	0.9	0.6	0.3	0.5	0.5
FR	0.7	0.9	0.6	0.5	1	0.9	0.8	0.9	0.5	0.6	0.2	0.6	0.7	0.4	0.8	0.6	0.4	0.5	0.4	0.6	0.4	0.5	0.9	0.4	0.5	0.6
GER	0.9	0.9	0.9	0.7	0.9	1	0.7	0.7	0.5	0.9	0.2	0.4	0.4	0.5	0.9	0.6	0.4	0.9	0.6	0.5	0.4	0.6	0.9	0.5	0.6	0.6
UK	0.4	0.7	0.6	0.5	0.8	0.7	1	0.6	0.9	0.8	0.3	0.5	0.5	0.4	0.8	0.4	0.3	0.5	0.3	0.2	0.6	0.3	0.6	0.4	0.5	0.5
IT	0.9	0.5	0.5	0.5	0.9	0.7	0.6	1	0.5	0.6	0.2	0.6	0.7	0.4	0.9	0.9	0.4	0.5	0.3	0.7	0.4	0.3	0.6	0.7	0.6	0.9
IE	0.2	0.5	0.5	0.4	0.5	0.5	0.9	0.5	1	0.8	0.3	0.5	0.5	0.4	0.6	0.4	0.2	0.4	0.3	0.3	0.7	0.3	0.5	0.3	0.4	0.4
NL	0.6	0.9	0.7	0.7	0.6	0.9	0.8	0.6	0.8	1	0.2	0.4	0.4	0.4	0.6	0.5	0.3	0.5	0.5	0.3	0.5	0.4	0.8	0.4	0.5	0.5
NOR	0.2	0.3	0.3	0.4	0.2	0.2	0.3	0.2	0.3	0.2	1	0.2	0.3	0.5	0.3	0.2	0.1	0.2	0.3	0.2	0.4	0.3	0.2	0.2	0.2	0.2
PO	0.4	0.5	0.4	0.3	0.6	0.4	0.5	0.6	0.5	0.4	0.2	1	0.9	0.5	0.6	0.5	0.3	0.5	0.3	0.5	0.2	0.3	0.4	0.4	0.4	0.4
ES	0.4	0.5	0.4	0.4	0.7	0.4	0.5	0.7	0.5	0.4	0.3	0.9	1	0.5	0.7	0.6	0.4	0.5	0.3	0.6	0.3	0.3	0.5	0.4	0.5	0.5
SW	0.6	0.6	0.8	0.9	0.4	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5	1	0.6	0.6	0.4	0.3	0.5	0.7	0.4	0.5	0.7	0.5	0.3	0.4
CH	0.9	0.7	0.6	0.6	0.8	0.9	0.8	0.9	0.6	0.6	0.3	0.6	0.7	0.6	1	0.6	0.3	0.7	0.4	0.6	0.3	0.4	0.8	0.5	0.5	0.5
HR	0.7	0.5	0.4	0.4	0.6	0.6	0.4	0.9	0.4	0.5	0.2	0.5	0.6	0.4	0.6	1	0.4	0.6	0.4	0.7	0.3	0.4	0.5	0.9	0.8	0.9
CY	0.4	0.3	0.3	0.2	0.4	0.4	0.3	0.4	0.2	0.3	0.1	0.3	0.4	0.3	0.3	0.4	1	0.3	0.3	0.8	0.1	0.3	0.3	0.4	0.4	0.4
CZ	0.9	0.6	0.6	0.5	0.5	0.9	0.5	0.5	0.4	0.5	0.2	0.5	0.5	0.5	0.7	0.6	0.3	1	0.6	0.4	0.4	0.6	0.7	0.5	0.9	0.6
EST	0.7	0.5	0.7	0.9	0.4	0.6	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.7	0.4	0.4	0.3	0.6	1	0.3	0.3	0.9	0.5	0.4	0.5	0.5
GR	0.6	0.3	0.3	0.3	0.6	0.5	0.2	0.7	0.3	0.3	0.2	0.5	0.6	0.4	0.6	0.7	0.8	0.4	0.3	1	0.1	0.4	0.4	0.7	0.6	0.6
IC	0.3	0.3	0.4	0.5	0.4	0.4	0.6	0.4	0.7	0.5	0.4	0.3	0.3	0.5	0.3	0.3	0.1	0.4	0.3	0.1	1	0.3	0.3	0.2	0.2	0.2
LI	0.4	0.5	0.7	0.9	0.5	0.6	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.7	0.4	0.4	0.3	0.6	0.9	0.4	0.3	1	0.4	0.4	0.5	0.5
LUX	0.5	0.9	0.7	0.6	0.9	0.9	0.6	0.6	0.5	0.8	0.2	0.4	0.5	0.5	0.8	0.5	0.3	0.7	0.5	0.4	0.3	0.4	1	0.4	0.5	0.6
SE	0.6	0.5	0.4	0.3	0.4	0.5	0.4	0.7	0.3	0.4	0.2	0.4	0.4	0.3	0.5	0.9	0.4	0.5	0.4	0.7	0.2	0.4	0.4	1	0.7	0.7
SK	0.9	0.6	0.5	0.5	0.5	0.6	0.5	0.6	0.4	0.5	0.2	0.4	0.5	0.4	0.5	0.8	0.4	0.9	0.5	0.6	0.2	0.5	0.5	0.7	1	0.9
SL	0.9	0.6	0.5	0.5	0.6	0.6	0.5	0.9	0.4	0.5	0.2	0.4	0.5	0.4	0.5	0.9	0.4	0.6	0.5	0.6	0.2	0.5	0.6	0.7	0.9	1

Abbreviations: AT: Austria, BE: Belgium; DK: Denmark; FI: Finland; FR: France; DE: Germany, UK: United Kingdom; IT: Italy; IE: Ireland; NL: Netherlands; NO: Norway; PO: Portugal; ES: Spain; SW: Sweden; CH: Switzerland; CZ: Czech Republic; ET: Estonia; GR: Greece; IC: Iceland; LI: Lithuania; LU: Luxembourg; SE: Serbia; SL: Slovenia; SK: Slovakia; CY: Cyprus. Sources: Own estimations

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