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Guarantees of Origin for Green Energy

Granular Green Electricity Certification for a Market-based Energy Transition

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Guarantees of Origin for Green Energy – Granular Green Electricity Certification for a Market-based Energy Transition

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SUMMARY

Getting electricity market design right is vital for efforts to expand renewable energies and achieve Germany's ambitious climate targets. As a market-based instrument, Guarantees of Origin can ease the path towards climate neutrality by fostering the growth of renewable energies. An efficient market design for Guarantees of Origin is therefore an important building block for a market-based energy transition and the achievement of climate targets. This study shows how the introduction of granular Guarantees of Origin could support the integration of renewables in the electricity market by better reflecting the physical reality of electricity generation and providing an important price signal for flexibility.

A Guarantee of Origin is an electronic certificate indicating the generation of one megawatt hour of renewable electricity in a specified period. Demand for Guarantees of Origin has grown significantly across Europe since 2016. This has been driven by steady growth in overall electricity demand on the one hand, and by the regulatory framework, which now affords European Guarantees of Origin a more prominent role in the context of the energy transition. In addition, there is growing awareness among end consumers and companies of the available options to source electricity from renewable energies. This growth in demand has been accompanied by an increase in the supply of Guarantees of Origin that has been driven by the expansion of renewables. The future development of the market for Guarantees of Origin will be shaped by a range of factors. A Norwegian exit from the European trading system would reduce the number of certificates on the market and push up prices. Lifting the prohibition of double marketing, a step that is currently being discussed in the context of the reform of the European Renewable Energy Directive, would significantly increase the supply of German Guarantees of Origin and thus not only dampen prices, but could potentially turn Germany from an importer to an exporter of Guarantees of Origin. As Guarantees of Origin can also be used to document the generation of green hydrogen, the ramp-up of the hydrogen market could also increase demand and again exert upward pressure on prices.

In Germany, Guarantees of Origin are issued with a yearly granularity. This lack of specificity does not reflect the high intermittency of renewable energy generation and instead assumes a fictitious world in which green electricity can be stored and dispatched at no additional cost and in unlimited quantities throughout the year. It also leaves them open to accusations of *greenwashing* and claims that companies are selling grey electricity as green electricity. Annual accounting creates a range of false incentives and enables consumers to meet their demand for green electricity with any renewable generation technology, regardless of its feed-in profile. It is only necessary that total annual production matches annual consumption, regardless of the time of production. As a consequence, the entire annual consumption can be covered by Guarantees of Origin issued for renewable electricity produced from solar, for example, even though these installations do not feed into the grid at night. The price signal of Guarantees of Origin thus ignores physical reality and distorts investment priorities: This encourages investment in what is considered to be the most affordable sustainable technology, without considering broader issues of system integration.

In order to better understand the ability of the different renewable technologies to fulfil specific demand trajectories, we first examine the potential coverage profiles of photovoltaics, onshore wind, and offshore wind. In a second step, we define the coverage rate of a renewable technology as the share that this technology can contribute to the fulfilment of possible demand profiles. As the coverage rate for all three technologies lies below 100 %, there is a need to

compensate for fluctuations by providing for additional storage or building in flexibility mechanisms. In the absence of such solutions, electricity produced in excess of needs cannot be used to achieve higher coverage in hours with less renewable production. In a second step, we compare this coverage against market-based procurement costs secured through long-term Power Purchase Agreements (PPAs). Building on this, we are able to determine the cost at which each technology can cover a specific share of hourly electricity consumption. The highest and lowest PPA prices are for photovoltaics and offshore wind, respectively. However, photovoltaics has the lowest hourly share. Weighting the PPA price by the coverage rate reveals that, in relation to their share, the actual procurement costs make photovoltaics the most expensive of the available technologies. This analysis shows how annual Guarantees of Origin translate into misaligned incentives that impact consumers: When Guarantees of Origin are accounted on an annual basis, photovoltaics appear to be the most affordable way to meet consumer demand for renewable energy, when in fact it is significantly more expensive than both onshore and offshore wind when hourly coverage is taken into account.

Options to improve flexibility are indispensable to the integration of renewables into the grid. The aim is to close the gap between consumption and renewable energy generation. Appropriate incentives will be needed to achieve this. Hourly Guarantees of Origin can provide important price signals to stimulate investment in flexibility options such as batteries and other storage technologies. With more renewables feeding into the grid, Guarantees of Origin and green electricity become more affordable. This makes it advantageous to draw on flexibility technologies in hours when renewable generation is reduced. The adoption of hourly Guarantees of Origin would also set incentives for demand flexibility: Lower prices make it efficient to shift demand to hours with high renewable generation. Hours when the share of renewable energy is particularly low are attractive for flexibility, as the price for Guarantees of Origin is likely to be higher at these times. Although the overall share of renewables is increasing and the share of hours with a high share of renewables is also increasing, our analysis shows that even in 2030 and 2035 there will still be a large share of so-called 'critical hours' in which renewables represent only a small share of the supply. In addition, we must assume that demand for hourly green electricity tariffs will grow parallel to the share of renewables. In this case, growth in supply will be matched by increased demand. These fluctuations in the share of renewables and demand translate into flexibility incentives with varying degrees of granularity. On the one hand, hourly shifts in price throughout the day encourage short-term flexibility. On the other hand, the share of renewables also fluctuates on a weekly and seasonal basis, which is reflected in differences in the price of Guarantees of Origin. These variations in pricing set incentives for medium-term and long-term flexibility.

Based on this analysis, we recommend the introduction of hourly Guarantees of Origin, ideally at the European level, in order to improve their synchronicity with physical electricity consumption. Other positive effects include a meaningful price signal and improvements in transparency for end consumers, thereby countering accusations of *greenwashing*. In conclusion, the incentive effects of different parameterisations should be investigated as a contribution to the development of a suitable market design.

CONTENTS

1 INTRODUCTION

Germany has set itself ambitious climate goals in response to the climate crisis and aims to achieve a 65 % reduction in greenhouse gas emissions compared to 1990 by 2030 and an 88 % reduction by 2040. A target date for achieving climate neutrality has been set for 2045 (BMWi 2021). The expansion of renewables is an important building block on the way to achieving these goals. Their share of gross electricity production is to rise to 65 % by 2030 (Bundesregierung 2021), and possibly even to 80 % under the terms of the recent coalition agreement (FDP, Bündnis 90/Die Grünen, SPD 2021).

The success of efforts to expand renewables will rest on both investment incentives and, specifically, incentives that will foster their integration into energy systems. This is where smart market design will play a pivotal role. EPICO and the Konrad-Adenauer-Stiftung previously outlined innovation-oriented recommendations for the development of a suitable market design in the *Policy Accelerator for Climate Innovation* (EPICO 2021a). The solutions identified include a digital, cross-border and temporally granular approach to green electricity marketing as a critical element of an innovative market design. This would help to strengthen investments in the field of renewable energies and flexibility technologies. Fluctuations in energy production from renewable technologies make it necessary to balance this volatility through the use flexibility technologies, which are characterised by their ability to quickly shift between feed-in and consumption. Batteries capable of storing large quantities of electricity are one example of these technologies. Flexibility can also be located on the consumer side with shifts in demand. These investments support the decarbonisation of the electricity sector and other sectors through electrification or conversion to green hydrogen. Guarantees of Origin (GOOs) are an important instrument for green electricity marketing, as they enable end consumers to prove the share of renewables in their electricity consumption.

At present, GOOs are issued for an annual accounting period. In failing to adequately represent the physical reality of the grid, this approach impedes innovation and hampers the refinancing of renewables on the market. The lack of specificity that currently characterises GOOs fails to reflect the high intermittency of renewable energy generation and instead assumes a fictitious world in which green electricity can be stored at no additional cost and in unlimited quantities throughout the year.

This study expands on the solution developed in the *Policy Accelerator* of granular GOOs and outlines their potential to support the system integration[1] of renewables by providing a price signal for more flexibility. In a first step, we explain the existing market design and regulatory framework governing the use of GOOs. Following on from this, we identify the false incentives that arise through the annual settlement of GOOs. We then consider hourly GOOs as one possible solution and examine the incentives they would set. In order to understand the impact of hourly GOOs, we explore both the ability of different renewable technologies to meet the hourly electricity demands of various consumers and the respective costs. This analysis reveals a flexibility gap that must be closed. In the last chapter, we show that hourly GOOs set flexibility incentives by sending a price signal that would promote improvements in the system integration of renewable energies.

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[1] in order to ensure the supply of renewable electricity, integration into the electricity grid must be ensured in addition to the expansion of renewable power plants.

2 OVERVIEW OF THE MARKET FOR GUARANTEES OF ORIGIN

2.1 Guarantees of Origin as a building block of energy markets

2.1.1 Definition and purpose

A Guarantee of Origin (GOO) is an electronic certificate indicating the generation of one megawatt hour of renewable electricity. The certificate enables end consumers to prove that a given share of their total electricity consumption was produced from renewable energy sources (RE). GOOs are issued to producers for the amount of renewable electricity they generate and feed into the grid. This enables RE producers to generate revenue on the basis of both the amount of electricity supplied to markets *and* its green credentials. GOOs specify the technology used to generate the energy unit and its location, and can be issued, traded, and cancelled in the twelve months following production in accordance with (EU) Directive 2018/2001 on the Promotion of the Use of Energy from Renewable Sources. GOOs are managed within a European system and can be traded across borders.

In Europe, GOOs were introduced in 2001 under the first directive for promoting electricity from renewable sources as a mechanism that was set apart from the physical electricity market. They were established with the aim of providing consumers with a reliable means of verifying what share of their electricity consumption was produced using renewable sources. While they do represent an additional source of revenue, GOOs were not intended to serve as an additional financing instrument for renewables.

2.1.2 Market design and institutions

When a megawatt hour of renewable electricity is generated, a Guarantee of Origin (GOO) may be issued under the circumstances explained in the following. The certificates are registered by national authorities or institutes in a designated register.

In Germany, this task is performed by the German Environment Agency (UBA), which operates the Register of Guarantees of Origin (HKNR). UBA has been a member of the European Association of Issuing Bodies (AIB) since 2016. Due to this, GOOs issued in Germany can be traded throughout Europe. The AIB developed the *European Energy Certificate System* (EECS), a framework that establishes harmonised standards for GOOs within Europe and facilitates energy certificate trading. The system aims to bolster objectivity and transparency in relation to green electricity.

When a GOO issued in Germany is registered in the HKNR, the EECS is automatically notified due to the former's membership in the AIB. Utility companies can purchase and sell GOOs, including their green credentials, independently of the energy to which they relate. When a Guarantee of Origin is sold to an end consumer, it is cancelled and may not be used further. This ensures, on the one hand, that each megawatt hour purchased in combination with a Guarantee of Origin has in fact been produced and, on the other hand, that each Guarantee of Origin is only issued and cancelled once.

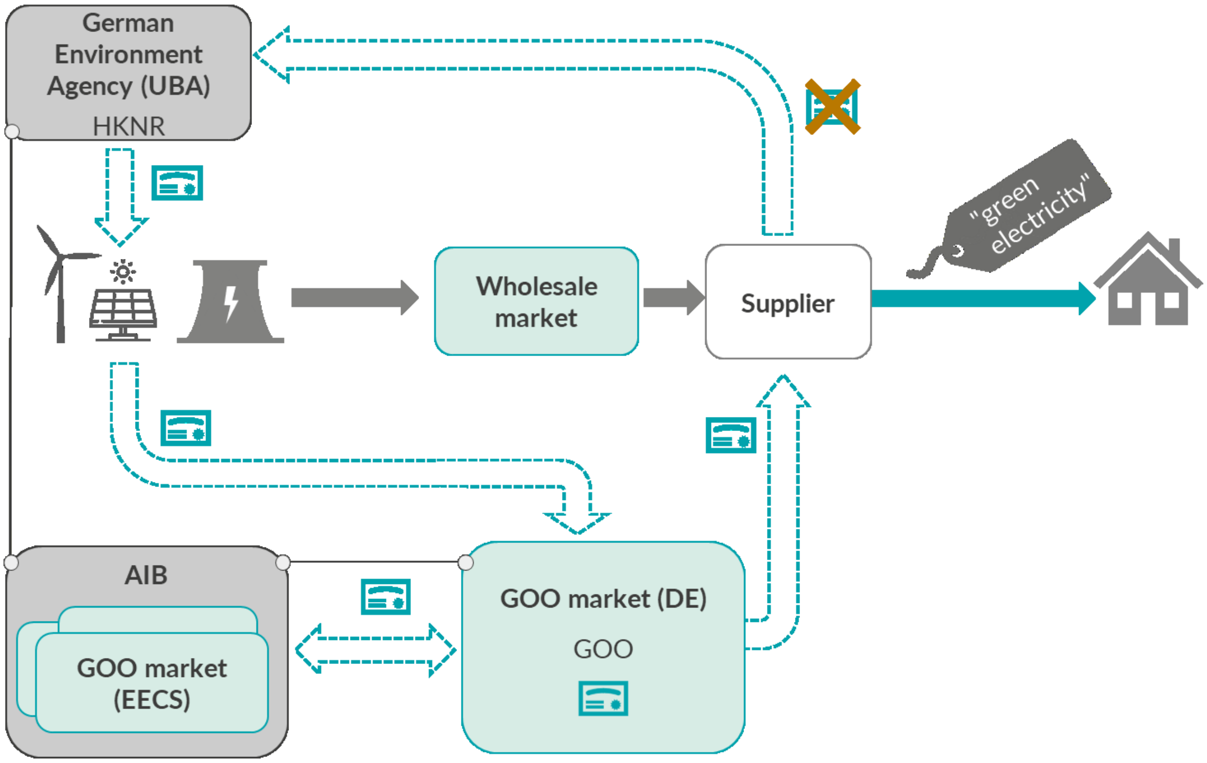


Figure 1: Trade in Guarantees of Origin in Germany (authors' representation)

The price of GOOs is determined by supply and demand. While central auctions held in some countries for GOOs – mainly those issued for state-subsidised installations – provide a transparent price signal, Germany has chosen to implement over-the-counter trading, i.e. bilateral rather than exchange-based trading. However, EPEX SPOT, the European electric power exchange, plans to introduce monthly multilateral auctions for GOOs in selected countries that are part of the EECS in 2022. Buyers and sellers will then be able to bid for both specific and general GOOs. Observers anticipate that this will increase market liquidity. Several levels of specificity within three dimensions will be made available: country, technology and subsidy regime. Indices will be published in the wake of each auction (EPEX SPOT 2021).

2.2 Regulation of Guarantees of Origin

2.2.1 The regulatory framework for Guarantees of Origin in Germany and Europe

Guarantees of Origin (GOOs) are regulated at both the European and national levels.

European law requires that GOOs be used to demonstrate the share of renewable energy in a supplier's total deliveries to its customers. The current regulatory framework for GOOs in Europe is governed by Directive (EU) 2018/2001 on the Promotion of the Use of Energy from Renewable Sources (Europäische Kommission 2018). Article 19 stipulates that GOOs are of the standard size of 1 MWh and may be issued by Member States at the request of a producer of energy from renewable sources. GOOs are valid for a period of 12 months after the production of the relevant energy unit and can be issued, traded, and cancelled within this time. The directive also stipulates that GOOs must at minimum include information on the energy source, sector, and the specific installation that produced the energy unit. The principle of mutual recognition also applies to GOOs within the European Union.

The provisions of the directive have been implemented in Germany in the Renewable Energy Sources Act (EEG 2021). Article 79 establishes the broad responsibilities of the German Environment Agency and provides for the issuance, transfer and cancellation of GOOs. Further details are regulated in the Implementing Regulation on GOOs [*Durchführungsverordnung über Herkunftsnachweise*]. Germany makes use of the option provided in Article 19 of Directive (EU) 2018/2001 not to issue GOOs to producers that receive financial support from a support scheme. This is specified in Article 80 of the EEG 2021 as the “prohibition of double marketing”. This stipulation is based on the assumption that the energy unit’s green credential has already been paid for by the end consumer through the EEG surcharge and that consumers should accordingly be protected from the undue burden of additional costs. This tends to result in higher prices in tenders for the promotion of renewable energies, as income from GOOs cannot be priced into bids. Germany’s ban on double marketing is atypical and most of the other Member States issue GOOs for subsidised installations; either to the operators directly or through central auctions.

2.2.2 Future developments in the regulatory landscape

Guarantees of Origin (GOOs) are becoming increasingly important in energy debates. Under the European Green Deal, the Renewable Energy Directive is to be amended as part of the “Fit for 55” climate and energy package (Europäische Kommission 2021). In this context, Article 19 on Guarantees of Origin will also be fundamentally revised. The option of declining to issue GOOs to subsidised renewable energy installations will be scrapped as part of these amendments. This would end the prohibition of double marketing in Germany and increase the number of GOOs issued in Germany. This increase in the absolute number of available GOOs is expected to push down prices. The legislative reform process is already well advanced. A two-year implementation period typically follows the adoption of such legislative changes. The lifting of the ban on double marketing would accordingly take effect from 2024/2025.

GOOs are also mentioned in the coalition agreement of the new federal government, which proposes a strengthening of the European trade in GOOs to support climate protection (SPD, Bündnis 90/Die Grünen, FDP 2021). Concrete plans for the implementation of this measure are not yet available.

2.3 The market situation for Guarantees of Origin

2.3.1 Guarantees of Origin in figures

In the following, we take a closer look at the market situation for Guarantees of Origin (GOOs), with a particular focus on "supply" and "demand". The "supply" corresponds to the quantity of GOOs issued, while "demand" corresponds to the quantity of GOOs cancelled.

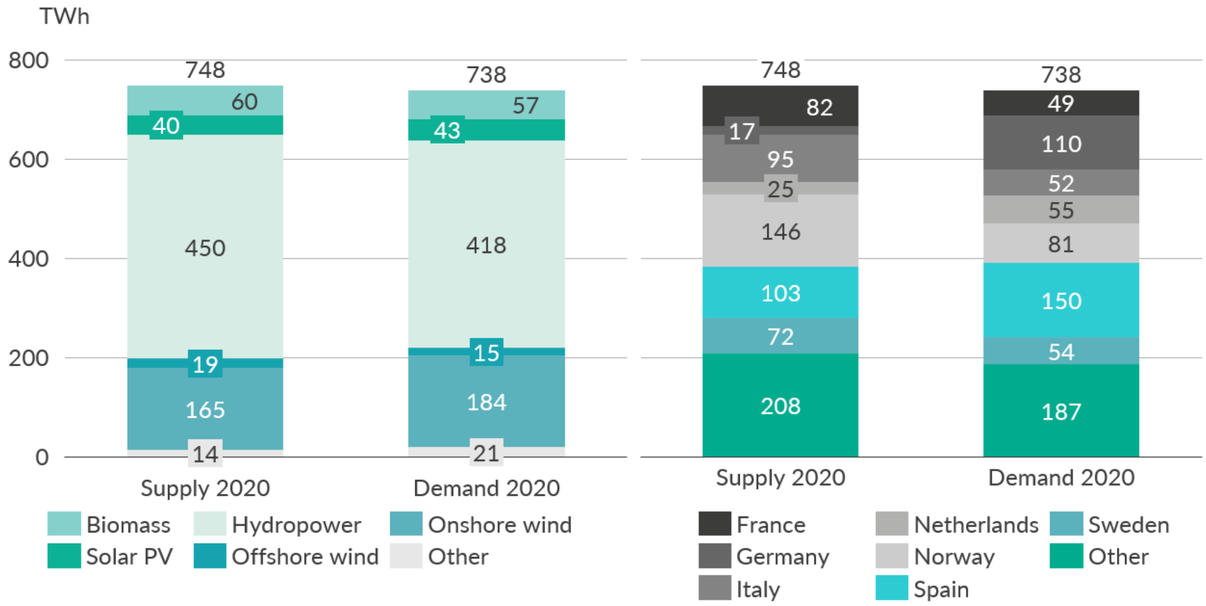


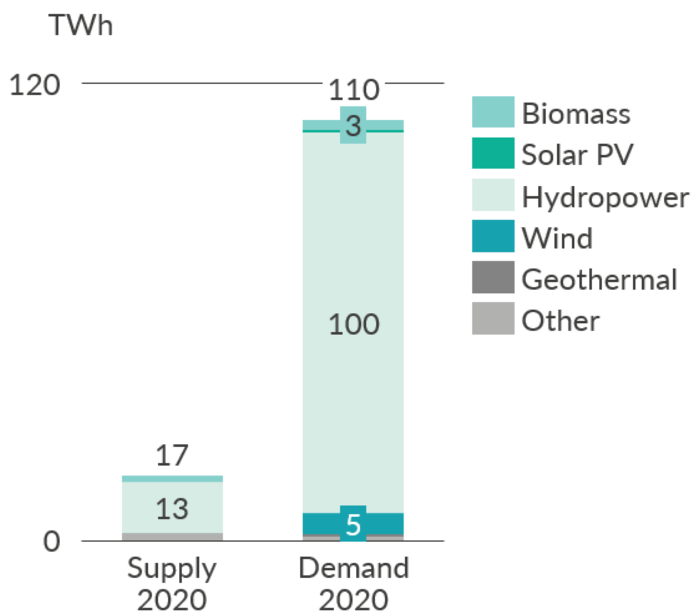
Figure 2: Supply and demand for Guarantees of Origin in 2020, by technology and country (Aurora Energy Research 2021a)

Figure 2 depicts the respective supply and demand volumes of GOOs in Europe by technology and country for the year 2020. In this example, the supply of GOOs in Europe totalled 748 terawatt hours (TWh), with hydropower accounting for over half of this. Onshore wind, which accounted for roughly one fifth of the certificates issued, was the second largest source of registrations. Demand is specified alongside supply. According to the figure, 738 TWh of GOOs were cancelled in 2020. This difference between supply and demand can be explained by the fact that GOOs do not have to be cancelled in the calendar year in which they are issued. Rather, GOOs are valid for a period of 12 months after the production of the relevant energy unit. Due to this, supply and demand spillovers from the previous and following year occur.

Norway accounted for the largest market share in the supply of GOOs in Europe at around 20 %. This is due primarily to the fact that 95 % of the country's energy output derives from hydropower and the share of energy from renewable sources is accordingly very high in Norway. All this is reflected in the large number of GOOs issued in Norway. In Germany, on the other hand, the ban on double marketing, which prohibits the issuance of GOOs for subsidised installations, coupled with the lower share of renewables in the electricity generation mix (50.5 %), results in a significantly lower market share in the supply of GOOs (2%).

There has been an observable increase in demand across Europe since 2016. However, this trend slowed in the period 2019 and 2020 due to the Covid-19 pandemic, with electricity demand declining in this period. The broad increase in demand for GOOs has been driven, on the one hand, by steady growth in electricity demand and, on the other hand, by the regulatory framework, which, affords European GOOs a more prominent role in the context of the energy transition. There is also a growing awareness among end consumers and companies of the available options to source electricity from renewable energies.

The increase in demand and supply can also be observed in Germany: between 2016 and 2020, demand for GOOs increased by 31 %. Supply, on the other hand, increased by just 16 %. Figure 3 depicts supply and demand in Germany for 2020. At 110 TWh, Germany's demand is the second highest in Europe (Spain leads the field with 150 TWh), but this contrasts with a supply of just 17 TWh. As a consequence, 84 % of this demand must be covered by imports.



3*: Supply and demand for Guarantees of Origin in Germany for 2020, by technology (Aurora Energy Research 2021a)*

Trends in the pricing of GOOs are another important aspect of market analysis alongside the development of supply and demand. GOOs are traded bilaterally. Due to this, reference prices are not publicly available, which obscures historical price developments. Despite the lack of accessible data, it is possible to identify price ranges. In 2020, prices for GOOs in Germany ranged between €0.1 and €0.4/megawatt hour (MWh) (Hamburg Institut 2021). Recent reports indicate that prices have climbed since mid-April 2021, establishing a ceiling of 0.5 €/MWh. However, historical data show that GOOs were priced higher in the preceding years. In 2018, for example, the price in Germany reached €1.73/MWh (Umweltbundesamt 2019). Similar prices were seen in 2019. Prices are determined by supply and demand and accordingly reflect changes in the availability of GOOs. For example, 2018 and 2019 were very low rainfall years in the Nordic countries, resulting in diminished hydropower capacity due to lower reservoir levels. Since hydropower makes up the bulk of the electricity mix in this region, far fewer GOOs were issued for electricity from hydropower. The price of GOOs increased as a consequence.

The 2020 slump in prices caused by the Covid-19 pandemic was due, among other things, by a drop-off in demand for both electricity and, by implication, GOOs.

It is important to understand the difference in scale between the price signal sent by GOOs and that generated by the wholesale market. The aforementioned prices for GOOs represent just a fraction of the average wholesale price for electricity in Germany in 2020, which was €30.47/MWh (ENTSO-E 2021), and account for just 0.3 - 1.3 % of the total price. This means that the price signal of GOOs is currently weaker than that sent by the wholesale market and influences investment decisions to a far lesser degree.

2.3.2 Future market trends

The outlook for the future is defined significantly by regulatory uncertainty and it is difficult to predict how the pricing of Guarantees of Origin (GOOs) will develop. There are factors in play that will both drive and dampen prices.

Achieving Germany's climate targets will require a massive expansion of renewable energies. According to the governing coalition agreement, markets rather than state mechanisms will shape this next phase of the energy transition. Subsidies for renewables are to be discontinued when the coal phase-out has been completed. According to the agreement, the role of market-based instruments such as long-term power purchasing agreements (PPAs) is to be strengthened as Germany transitions to a zero-subsidy approach to the expansion of renewables Securing necessary investments in renewables requires a market design that will enable investors to generate sufficient revenues. GOOs can play a role in incentivising investment alongside the wholesale market and ancillary services.

The supply-side outlook

Anticipated gains in output from renewables will increase the supply of GOOs both in Germany and Europe. Supply growth exerts downward pressure on the pricing of GOOs. According to our calculations, the supply will increase by around 5 % per year (Aurora Energy Research 2021a), reaching approx. 1060 TWh Europe-wide in 2030. The supply in Germany is expected to climb from 23 TWh in 2021 to 61 TWh in 2030. This calculation does not take into account the new renewable expansion targets set in the coalition agreement or the possible scrapping of the double marketing ban as Germany moves to implement the EU's Renewable Energy Directive. These two developments could lead to massive gains in the supply of German GOOs. Looking to the technology mix underpinning German GOOs, we anticipate that the total number of GOOs from hydropower will remain constant. Under the double marketing ban, GOOs can only be issued for electricity from zero-subsidy installations. With some renewable installations reaching the end of their support period and the recent success of zero-subsidy bids in tenders for offshore wind, we expect that offshore wind installations will account for a substantial share of the market-based expansion of renewable energies and, by implication, the available supply of GOOs. The scrapping of the double marketing ban would enable German GOOs to be issued for electricity from subsidised renewables as well. The resulting technology mix would reflect the prevailing renewables generation mix in Germany.

The demand-side outlook

Growth on the supply side is set to be paralleled by demand-side gains. On the one hand, electricity demand is expected to recover in the wake of the pandemic and sector coupling and electrification will lead to higher electricity demand across all sectors. On the other hand, demand for green power is growing, driven by corporate and industry sustainability goals and increased demand from households for renewable and locally generated power. Rising demand exerts upward pressure on the price of GOOs. We expect demand to increase by 6 % per year, with absolute demand across Europe reaching 1,341 TWh (in Germany: 206 TWh) in 2030 (Aurora 2021a). Whether Germany remains an importer in the coming years depends to a significant degree on the development of the regulatory framework. If GOOs continue to be restricted to non-subsidised installations, Germany will only be able to cover 29 % of its demand through the national supply and would remain an importer (Aurora 2021a). However, if the ban on double marketing is lifted, the number of GOOs issued in Germany would grow substantially. We calculate that renewable generation capacity will reach 324 TWh in 2030 under the Aurora Central Scenario (Aurora 2021b). A change in policy that would see GOOs issued for all electricity generated would make Germany an exporter.

The hydrogen market ramp-up

The market ramp-up of green hydrogen is another important factor in the future development of the market for GOOs. The ramp-up of the European hydrogen market has implications for GOOs, as these can be used to prove that electricity drawn from the grid to produce hydrogen derives from renewable sources. Both the German and the European hydrogen strategy identify GOOs as an important instrument for the market ramp-up of green hydrogen (BMWi 2020, European Commission 2020). This would be the case in particular if the principle of additionality is included in the future regulatory framework for renewable hydrogen. This would require that renewable energy generation capacities be expanded to match the growth of hydrogen generation capacities. The principle aims to ensure that additional renewable energy consumption is covered by additional renewable energy capacity. Under the Renewable Energy Directive this principle is to be applied to renewable hydrogen. It is also necessary to ensure that the production of hydrogen does not restrict the availability of renewables for electricity production. Another important criterion established by the Renewable Energy Directive for renewable hydrogen is temporal correlation. According to the directive, renewable fuels cannot be counted as fully renewable if the hydrogen is produced at a time when the contracted renewable generation unit is not generating electricity. The requirement that hydrogen generation be powered exclusively by additional renewable installations and in correlation with renewable electricity production makes the production of renewable hydrogen both more expensive and more complex. These criteria pose regulatory hurdles for the development of the European hydrogen market and their details are hotly debated. The European Commission is currently drafting a delegated act to further clarify the application of the principle of additionality. The first draft sets ambitious requirements for both additionality (electrolysers must be powered by an additional renewable energy source that has come online in the 12 months preceding the commencement of operations) and temporal correlation (electricity from a renewable plant must be consumed by the electrolyser within a 15-minute window).

The regulation of these criteria could be managed using GOOs, however not in their current form. Further information specifying the additionality of renewable sources as well as finer temporal granularity would need to be added to GOOs in order to reflect these new requirements.

Quality characteristics of Guarantees of Origin

Quality characteristics such as regionality and additionality also influence the price of GOOs. While the pricing of GOOs lacking such characteristics tends to track that of Norwegian hydropower certificates, certain characteristics act as value drivers for GOOs. Higher demand for local green electricity, partly resulting from regulatory requirements, has already driven up the value of GOOs in some countries. Dutch wind certificates, for example, trade at a premium. This development is due to the increased demand from industry and households for locally generated renewable electricity – in other words, for regionality. Swiss hydropower certificates also trade higher because they service local demand for renewable electricity generated in Switzerland. Increasing awareness of sustainability and demand for locally generated electricity on the part of end consumers is likely to result in an increase in demand for regional electricity throughout Europe. The application of the principle of additionality to the hydrogen market would also heighten demand for GOOs with this quality. In light of this, we anticipate that the market for GOOs will diversify, resulting also in more price differentiation. The quality characteristics of GOOs will play a greater role in future. This will also impact on incentive effects for the renewables build-out in countries with comparatively unfavourable renewable energy potentials.

Norway's possible withdrawal from the European GO market system

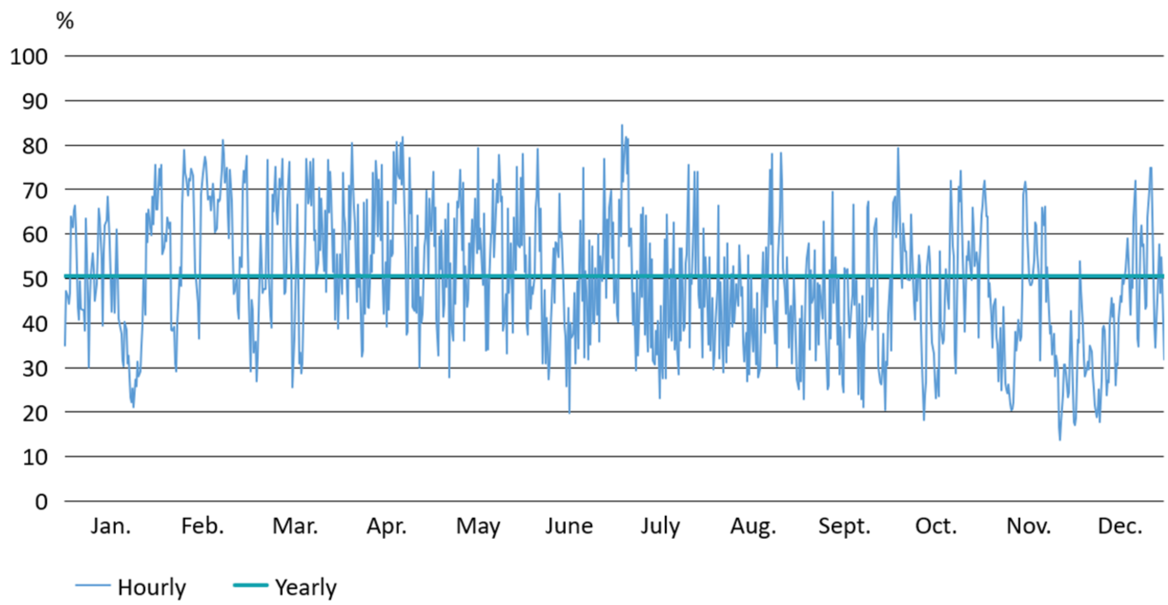
Another important factor in the future development of the market is the possibility that Norway could leave the European market system for GOOs. In October 2021, the Norwegian government announced its intention to withdraw from the European trading system for GOOs in order to prioritise the electricity needs of Norwegian industry, which, due to the strong export performance of Norwegian GOOs, is only able to access "grey electricity" in some areas, i.e. electricity without green credentials (Montel 2021). A Norwegian exit would have significant impacts. As the largest issuer of GOOs, Norway plays a pivotal role in the European market. In 2020, Norway accounted for a market share of 20 % of the European supply, with significant volumes exported to Germany and the Netherlands in particular. Norway is also an important trading platform, as transaction costs are lower under the Norwegian system. Due to its high market share, Norwegian GOOs from hydropower often serve as a benchmark for prices on the wider European market. A Norwegian withdrawal would constrict the supply of GOOs to the European market. The drop-off could amount to around 146 TWh in total (Aurora 2021a). Norwegian GOOs would no longer serve as a benchmark price.

The price-increasing effect of a Norwegian exit from the European market system and decline in the supply of GOOs is limited by several factors. On the one hand, the absolute amount of GOOs issued in Norway will not change significantly, while the absolute amount in other European countries will increase as the build-out of renewables gains pace. Norway's market share is expected to decrease to about 12.5 % and, following short-term effects, will have a smaller effect on prices in the long run. On the other hand, these developments are likely to be overcompensated by a lifting of the double marketing ban, resulting in a significant increase in the supply of German GOOs, which would have a price-reducing effect. Under the Aurora Central Scenario we anticipate that output from renewables will reach 286 terawatt hours in Germany in 2025 (Aurora 2021b). This would more than compensate for the decline in the supply of Norwegian GOOs. Timing is the decisive factor here: if Norway's exit occurs parallel to the lifting of the ban on double marketing in Germany, the price-driving effect will be reduced and would possibly be overcompensated by the increased availability of German GOOs.

3 DRAWBACKS OF THE ANNUAL SYSTEM AND INCENTIVE EFFECTS OF AN HOURLY SYSTEM FOR GUARANTEES OF ORIGIN

3.1 The limits of the current system for Guarantees of Origin

Guarantees of Origin (GOOs) were introduced at a time when renewable energies still accounted for a small share of the energy mix. Since then, the share of renewables has increased massively. Renewables are weather dependent and therefore volatile – in other words, production from renewables is subject to fluctuation. As a consequence, the annual and hourly average share of renewables in the system diverge significantly. This is shown for the year 2020 in Figure 4 below. In 2020 renewable energies accounted on average for a 50.5 % share of electricity generation. The figure reveals that the hourly production of renewable energies differed substantially from this average: In July, the share of renewables reached 85 % of electricity generation, while in late November they accounted for as little as 13 %.



4*: Annual and hourly share of renewables in total electricity production in Germany in 2020 (Based on ENTSO-E 2021)*

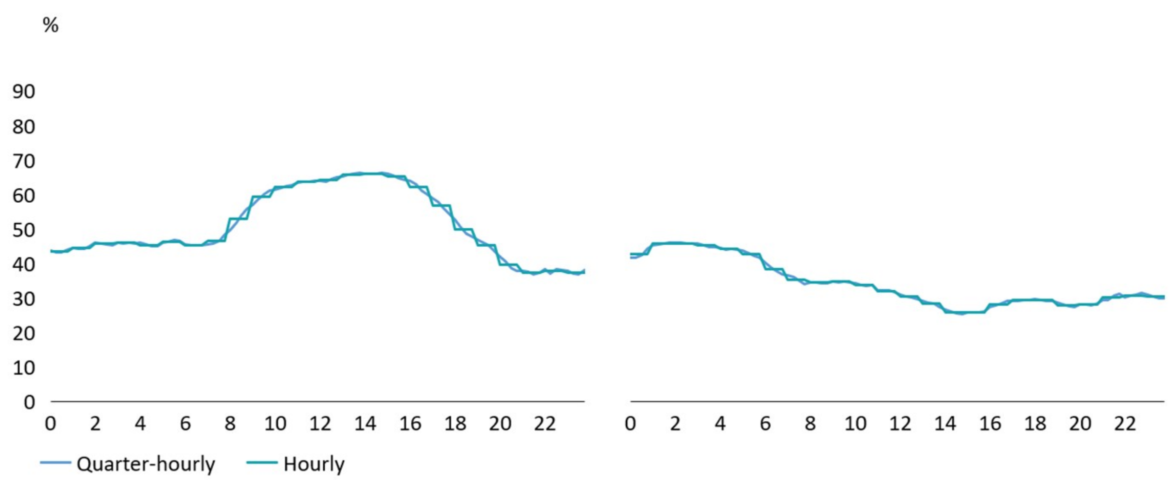
The physical electricity market has responded to these developments, for example by trading closer to real time and introducing finer product granularity. As a consequence, electricity consumption and generation are balanced in Europe at intervals of 15 minutes. In contrast, GOOs balance consumption and generation over an annual accounting period. This approach does not reflect physical reality as it means that a Guarantee of Origin, issued for a megawatt hour of renewable energy produced on a sunny day in spring, can be offset against electricity consumed on a windless winter night. This reflects the erroneous assumption that green electricity can be stored at no additional cost and in unlimited quantities throughout the year.

The use of an annual accounting period creates a range of false incentives and enables consumers to meet their demand for green electricity with any renewable generation technology, regardless of its feed-in profile. It is only necessary that total annual production matches annual consumption, regardless of the time of production. As a consequence, the entire annual consumption can be covered by GOOs issued for renewable electricity produced from solar, for example, despite the fact that solar installations do not feed into the grid at night. The price signal of GOOs thus ignores physical reality and distorts investment priorities by encouraging investment in what is considered to be the most affordable sustainable technology, without considering broader issues of system integration.

The use of an annual accounting period for GOOs also creates transparency deficits. The core objective of GOOs is to document for end consumers the renewable share of their electricity consumption. The annual accounting system fails to provide sufficient granularity to achieve this and can only provide a rough picture based on average values rather than a true approximation between consumption and renewable generation. This has led to accusations that GOOs are an instrument for corporate greenwashing.

3.2 The optimal granularity for Guarantees of Origin

It is important to define more precisely what we mean by *granular* Guarantees of Origin (GOOs). Various degrees of granularity could be applied to GOOs: from the status quo of annual settlement to monthly, daily, hourly, quarter-hourly or even minute-by-minute resolution. The finer the granularity, the more marginal the optimisation gains achieved by more closely reflecting physical reality become; while the annual renewables average differs significantly from the hourly average, there is little difference between hourly and quarter-hourly GOOs. The latter are depicted in Figure 5, where the quarter-hourly renewable share differs only marginally from the hourly renewable share. The maximum relative deviation is 6.6 % in summer and 4.5 % in winter. These days are indicative rather than representative, but they illustrate the diminishing difference. These seasonal differences occur due to variations in the solar incidence angles of PV systems (which are often south-facing) over the course of the day. They are more pronounced in summer than winter and are more discernible in the quarter-hourly profile.



5*: Hourly and quarter-hourly share of renewables in total electricity generation on an indicative (i.e., non-representative) summer (left) and winter day (right) in 2020 (based on ENTSO-E 2021)*

However, higher granularity leads to higher transaction costs, among other things due to the shorter validity of the GOOs and increased accounting requirements. At a certain point, increasing granularity incurs more disadvantages (by pushing up transaction costs) than advantages (improved transparency). In the following, our analysis focuses on hourly GOOs, in particular as finer granularity would entail higher transaction costs without delivering significant gains in tracking physical generation, as seen above in Figure 5.

3.3 Improving system integration of renewable energies through an hourly Guarantee of Origin system

Integrating renewables in the electricity system becomes ever more challenging as their share of the mix increases. Parallel to this, cannibalisation effects also tend to arise because renewables generate electricity concurrently (due to their weather dependency), leading to falling prices in peak output hours, curtailing earnings. Options to improve flexibility and close the gap between consumption and generation are indispensable to improving the system integration of renewables. Possible solutions include storage solutions, improved demand flexibility, and the optimised management of renewable generation.

Appropriate incentives will be needed to achieve change. Hourly Guarantees of Origin (GOOs) can set important price signals that stimulate investment in flexibility. They make it possible to indicate the *hourly* rather than merely the *annual* share of electricity consumption derived from renewable sources. This approach would better reflect the actual availability of renewables.

Granular GOOs can also lead to an overall price increase: Increased consumer demand for 24/7 availability of green electricity will also increase demand in those hours when the share of renewables is lower. Taking a more realistic view of the availability of energy storage options, finer granularity exerts upward pressure on prices. On the one hand, higher prices incentivise the market-based financing of renewables. On the other hand, they also provide incentives to invest in the right generation technologies. Hourly granularity would cause the price of GOOs to fluctuate within the course of the day and to climb when fewer renewables feed into the grid relative to demand (e.g., at night). This would send a price signal to invest in technologies that can supply electricity at these price peaks, for example storage solutions and wind power. It would also encourage further optimization in the alignment of renewable technologies with grid requirements, for example the development of east-west facing photovoltaic installations or under-sizing wind turbine generators. In short, hourly GOOs would foster geographical and technical diversity in the deployment of sustainable generation and storage solutions by facilitating comparison of the benefits of different technologies for the energy system as a whole.

The price signal sent by hourly GOOs also sets incentives for demand flexibility. GOOs and green electricity are more affordable when the grid can draw on large numbers of renewables. This also makes it more cost effective to shift demand to hours with high renewable generation.

The interaction of the price signals sent by GOOs and the wholesale market is of particular interest. Flexible generation technologies are responsive to price signals. Currently, the dominant price signal is that of the wholesale market. It is shaped by both renewables and by conventional generation and demand. Granular GOOs would send an additional price signal to the market based on the supply of electricity from renewables: when the share of renewables is higher, the price of GOOs will tend to be low. Compared to annual GOOs, hourly GOOs are subject to far greater price volatility, yet also achieve significantly higher prices. This sends a stronger signal than current pricing and sets investment incentives. In particular, it incentivises consumption during hours with high renewable feed-in as well as feed-in during hours of low supply from renewables. This double price signal does not necessarily lead to the economically optimal outcome, as it distorts the incentives in favour of renewables. Take, for example, an hour when the supply of coal-based electricity is abundant and the feed-in from renewables is low. The wholesale price of electricity could be very low at this time, making it more efficient to increase consumption. However, if the price for GOOs trends higher in this hour, driven by the low share of electricity from renewables, this would set an incentive to reduce consumption. However, this leads to the improved integration of renewable energies by fostering the alignment of flexibility with feed-in from renewables.

3.4 Pilot projects and initiatives promoting granular Guarantees of Origin

With the first commercial pilot projects already under way, granular Guarantees of Origin (GOOs) have proved themselves in recent years, both as a theoretical concept and in the field. For example, corporate heavyweight Google has pledged to power its operations with 100% renewable electricity around the clock by 2030. (Google 2021). Hourly GOOs will be indispensable to verifying the success of Google's efforts. Ambitions to expand the granular market have also been expressed in the USA: under the *American Jobs Plan*, the Biden administration plans to use the federal government's purchasing power to procure 24/7 clean power for federal buildings (White House 2021).

France has also forged ahead and introduced monthly GOOs in 2021. Launched on 1 January 2021, the new model established monthly disclosure periods for electricity from renewable energy. French GOOs continue to be valid for a period of 12 months following the end of the production period to which they apply and are still settled on an annual basis. However, a national regulation stipulates that the month of production specified on a Guarantee of Origin must be identical with the month of consumption. This requirement aims to improve the alignment of GOOs with real-world consumption, strengthens their price signal, and enhances transparency for end consumers.

The idea of issuing and cancelling GOOs on an hourly basis has already been trialled by various initiatives and pilot projects. EnergyTag is presumably the largest initiative to pioneer granular GOOs (EnergyTag 2021). Launched in London in 2020 by Phil Moody, the founder of the European Association of Issuing Bodies (AIB), EnergyTag has set itself the goal of defining and building a market for hourly energy certificates. As was the case with GOOs, this initiative is led and driven by industry players. EnergyTag currently has about 60 members, including utility companies, energy consumers, grid operators, government agencies as well as non-governmental organisations and start-ups. EnergyTag aspires to make the energy market more transparent so that end users can access and verify the source of their green electricity in real time. EnergyTag has three main goals:

1. Establish standards for hourly Guarantees of Origin and guidelines for a market;
2. Coordinate pilot projects to demonstrate market development;
3. Highlight the importance of hourly Guarantees of Origin.

In one large-scale pilot project initiated through EnergyTag, Vattenfall supplied three data centres operated by Microsoft in Sweden with 100 % green electricity for every hour of the year. The project, which is now complete, marked a first step towards Microsoft's ambitious goal of using 100 % renewable energy 24/7 by 2025. Microsoft has also used the software platform FlexiDAO (also a member of EnergyTag) in a pilot project at one of its data centres in Amsterdam to cancel hourly certificates generated through offshore wind (FlexiDAO 2021)

In December 2021, the pan-European power exchange Nord Pool, which is also a member of EnergyTag, set itself the goal of developing a spot market for hourly GOOs in cooperation with tech start-up Granular (Nord Pool 2021). The partners plan to use Nord Pool's exchange infrastructure to develop a trading concept for hourly GOOs. Workshops to test the market design with participants from various European countries are scheduled to take place in 2022.

EnergyTag includes several actors from Germany among its members, including the Hamburg Institute and Berlin-based company Lumenaza, the creators of an SaaS platform for green utilities (Lumenaza 2021).

4 COVERAGE AND PROCUREMENT COSTS OF DIFFERENT RENEWABLE TECHNOLOGIES

4.1 Generation and demand profiles in annual and daily comparison

In the previous chapter, we showed that the share of electricity generation from renewable energy sources was highly volatile in 2020. This volatility varies in time and across different renewable technologies. In this chapter, we examine the coverage rates provided by photovoltaics, onshore wind, and offshore wind in order to better understand the capacity of different renewable technologies to fulfil specific demand trajectories.

The coverage rate is defined here as the share that a renewable technology can contribute to the fulfilment of a demand profile. On an hourly basis, potential demand coverage varies immensely between renewable technologies due to the significant differences in their respective feed-in profiles. While photovoltaics, for example, are dependent on the sun, with production peaking at midday, onshore and offshore wind power can potentially generate electricity through the night. Our analysis aims to show how this affects the coverage rates for different demand profiles, such as household and commercial customers. We also draw a comparison between coverage and pricing under so-called *Power Purchase Agreements* (PPAs) for different renewable energy sources. This analysis focuses on individual generation and demand profiles. We assess the hourly output of different renewable energy technologies and compare this against three typical demand profiles to calculate the coverage rate achieved by the individual technologies.

In the following analysis, we calculate the hourly coverage of various renewable technologies, assuming a normalised electricity consumption profile of 1,000 MWh per year and a normalised generation profile. This would provide 100% coverage over the course of the year, with overall generation matching overall demand. However, an examination of hourly data reveals fluctuations in electricity generation from renewables throughout the year. To map this hourly granularity, we examine hourly production and demand profiles that are characterised by considerable volatility. We anticipate that we will discover significantly lower average hourly coverage and significant seasonal and daily fluctuations. For this analysis, we examine three model demand profiles:

1. **Constant base-load profile**: Constant consumption totalling 1,000 MWh per year. This profile reflects the demand of large-scale industrial consumers with continuous operations (chemical plants etc.)
2. **Continuous commercial load profile**: Commercial consumers with a relatively even consumption pattern and constant base demand, such as sewage treatment plants, cold stores and drinking water pumps, normalised consumption of 1,000 MWh per year
3. **Household load profile**: Consumption pattern of a typical household with normal household fluctuations (high demand in the evening hours, minimum at night), normalised consumption of 1,000 MWh per year. This profile is based on a standard load profile procurement for several households

We model generation using generation profiles for photovoltaics, onshore wind, and offshore wind, also normalised to 1,000 MWh per year. The generation patterns are based on weather data for the year 2013. This was an average year, by our assessment, with no exceptional weather events. The rates of utilisation of the various renewable technologies, on the other hand, reflect long-term averages rather than the weather year.

In order to gain an overview of how the different generation technologies perform over the course of the year, Figure 6 depicts the generation profiles of photovoltaics, onshore wind, and offshore wind normalised to 1,000 MWh/year in hourly resolution. The constant base load profile is also depicted, which is also normalised to 1,000 MWh/year. The high volatility of the generation profiles is clearly evident. While in some hours of the year the individual renewable technologies generate more than is required to cover the base load profile, shortfalls occur at other times. As is evident here, all three technologies report a coverage rate of less than 100 %. This confirms our expectation and highlights the difference between the annual and hourly settlement of Guarantees of Origin (GOOs): Each technology produces 1,000 MWh over the course of the year and can provide 100% – assuming that GOOs are settled annually. However, hourly granularity reveals that although overall electricity generation and consumption match, the hourly production and consumption patterns differ substantially and complete coverage is not available in many hours. These fluctuations cannot be balanced out without additional storage or flexibility mechanisms. In the absence of such solutions, electricity produced in excess of needs cannot be used to achieve higher coverage in hours with less renewable production.

Figure 6 also highlights seasonal effects, with solar seasonality reducing coverage from photovoltaics in winter especially and seasonal effects reducing the coverage of onshore wind power in the summer months. The coverage of offshore wind, on the other hand, is relatively even.

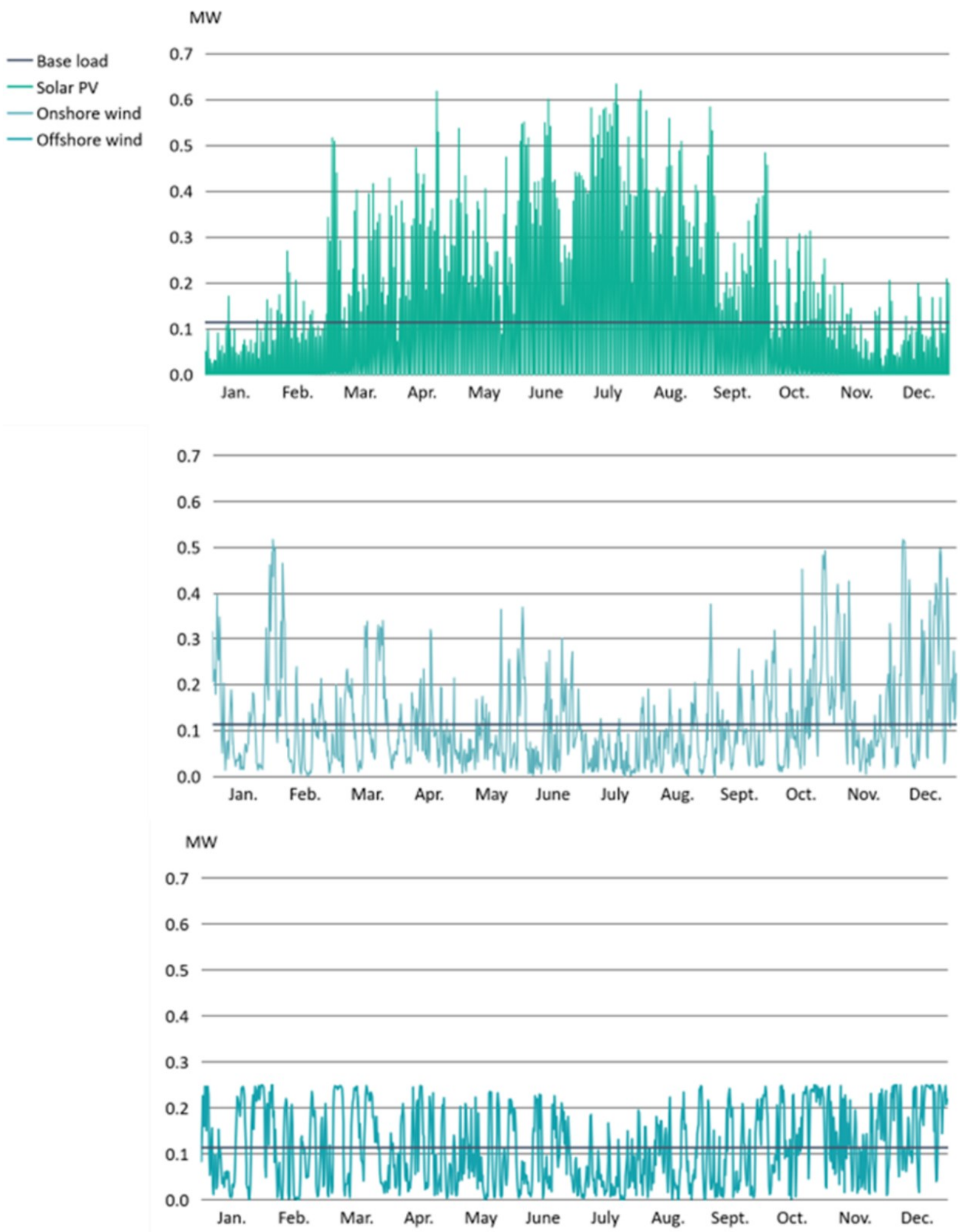


Figure 6: Annual renewable generation profiles and constant base load profile, normalised to 1000 MWh/year (Aurora Energy Research 2021b)

In a next step, we calculated the coverage rates of the respective technologies for each demand profile. These are listed in Table 1. Photovoltaics achieves a coverage rate of 40 % of the base-load demand profile; in other words, 40 % of base load consumption could be covered by PV on an hourly basis. This is the lowest annual coverage of the renewable technologies analysed here: Offshore wind achieves the highest coverage at 69 %, directly followed by onshore wind at 65 %. As anticipated, the coverage provided by photovoltaics is higher for the household demand profile than the base-load demand profile, as household demand peaks during the daytime, coinciding with the availability of more electricity from PV. The coverage provided by wind declines, on the other hand, reflecting a combination of reduced daytime coverage and surplus production at night.

Load profile	Solar PV	Onshore wind	Offshore wind
Base load	40 %	65 %	69 %
Continuous commercial operation	42 %	66 %	70 %
Household	44 %	63 %	67 %

Table 1: Coverage rates of photovoltaics, onshore wind and offshore wind for a constant base-load profile (Aurora 2021a), household profile (GVV Energie 2021) and load profile for continuous commercial operations (Stromnetz Berlin 2021). Standardised to 1.000 MWh/year, respectively.

In order to better illustrate the intra-day and seasonal differences in coverage, Figure 7 depicts the generation profiles of the assessed renewable technologies as well as the variable load profiles (commercial and household) for an average summer and winter day respectively. The profiles were calculated by averaging the hourly data for the months of June, July and August for the summer day (or December, January and February for the winter day). Table 2 details the coverage levels achieved.

As all of the generation technologies and load profiles utilised in this analysis are normalised to 1,000 MWh, the electricity generation and consumption depicted here does not reflect absolute real-world generation or consumption in the hours shown. For example, in Figure 7 onshore wind generation is higher than offshore wind generation. This is due to the fact that onshore wind feeds more electricity into the grid in winter than in other seasons, while offshore wind produces evenly throughout the year. With generation normalised to 1,000 MWh, onshore wind therefore feeds more into the grid in winter than offshore wind.

Figure 7 shows how renewable energy generation fluctuates throughout the course of a day. This is particularly evident for photovoltaics, with generation peaking at midday. Both onshore and offshore wind fluctuate to a lesser degree compared to photovoltaics. This is because the data depicted represents the average values for several months. While generation from photovoltaics follows a relatively clear pattern that is well replicated in the average values, both onshore and offshore wind are more erratic and these variations are smoothed out by averaging. Hourly fluctuations in wind generation are much more pronounced on individual days. Absolute wind generation can in fact be much lower at times, for example during the so-called “dark doldrums” (low wind periods at night).

There are also seasonal variations in the generation profiles of different renewables. Photovoltaics’ midday generation peak is much more pronounced in summer than in winter and more than covers the load profiles. This is also apparent in the respective coverage rates: While photovoltaics achieve a coverage rate of over 60 % for the household and commercial load profiles in summer, this drops to an average of 31-32 % in winter. In comparison, onshore and offshore wind generation are less variable and absolute generation levels are higher in winter. For example, offshore wind achieves a high coverage rate of 100% on average for the base load profile and 91% for the commercial profile in winter.

As these are seasonal average days, the coverage rates differ from the annual averages. The coverage rate for onshore and offshore wind is higher than the annual average in winter and close to the annual average in summer. The coverage rate of photovoltaics is above the annual average in the summer months and lower in winter.

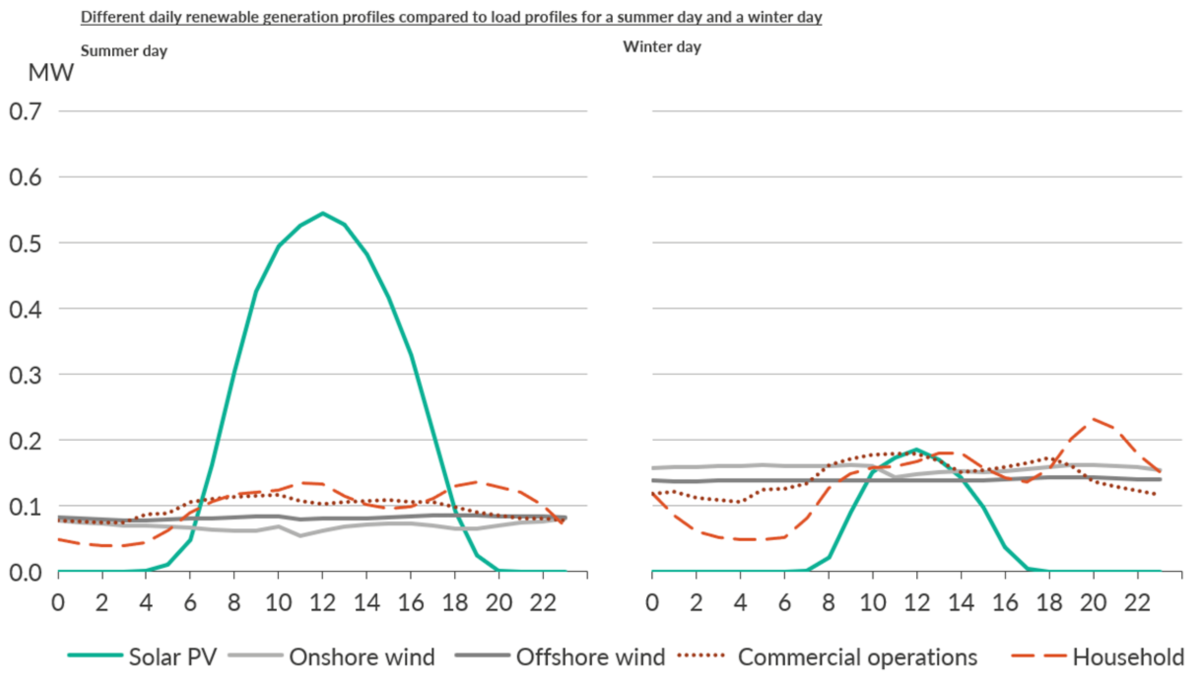


Figure 7: Different daily renewable generation profiles (Aurora 2021a) compared to load profiles for continuous commercial operations (GGV Energie 2021) and a household load profile (Stromnetz Berlin 2021) over the course of the day in summer (left) and winter (right)

Load profile	Summer day Solar PV	 Onshore wind	 Offshore wind	Winter day Solar PV	 Onshore wind	 Offshore wind
Base load	55 %	60 %	71 %	30 %	100 %	100 %
Continuous commercial operations	62 %	71 %	84 %	31 %	96 %	91 %
Household	64 %	63 %	75 %	32 %	91 %	85 %

Table 2: Average coverage rates in summer and winter for different load profiles (Own calculations based on Aurora 2021a, GGV Energie 2021, Stromnetz Berlin 2021)

4.2 Comparison of coverage rates and market-based procurement costs

In a second step, we compare the coverage rates achieved by different renewable technologies against market-based procurement costs under long-term Power Purchase Agreements (PPAs). Based on the results of this comparison, we determine the cost at which each technology can cover a specific share of hourly electricity consumption. PPAs are bilateral electricity supply contracts between two parties, typically between an electricity generator and an electricity consumer. PPAs establish a fixed price and volume of supply for a specific period (usually 8–15 years). These agreements reduce the market price risk, and thus lower financing costs for renewables while also providing a long-term procurement option for electricity consumers.

Due to the ban on double marketing in Germany, Guarantees of Origin (GOOs) cannot be issued for subsidised renewable energy installations. However, this restriction does not apply to PPAs, which are a market-based financing instrument. Obtaining GOOs under these terms enables electricity consumers to demonstrate and market the green credentials of the electricity. GOOs issued for electricity produced to supply a PPA are accordingly treated as price components.

To determine the price and cost of a particular technology, we calculate technology-specific prices for PPAs. Based on the Aurora Central Scenario, we calculated the PPA prices listed in Table 3 for photovoltaics, onshore wind, and offshore wind. These prices were calculated assuming contracts with a fixed price over a term of 10 years, starting in 2023, and an "*as produced*" delivery structure – reflecting this, the generation profile was not adapted. The modelling of the prices for PPAs is based on a method developed by Aurora, which takes the base load price, market values, risk assessments, Guarantee of Origin prices, and other factors into account in the calculation.

As shown in the table, the lowest and highest PPA prices are for photovoltaics and offshore wind, respectively. As the most affordable option, photovoltaic PPAs appear to be the best solution for consumers who wish to meet their annual demand with renewable electricity. However, as mentioned in the previous section, photovoltaics achieve the lowest hourly coverage rate for all of the assessed load profiles. And while the PPA price for photovoltaics is lower than that for onshore and offshore wind, photovoltaics cannot produce sufficient energy to cover demand in many hours of the year.

In order to make the costs for the different technologies comparable despite their different coverage levels, we divided the PPA price by the coverage rate for each of the different load profiles. This quotient reflects the relative cost of the technology per coverage and can be interpreted as a kind of "price-performance ratio" in terms of coverage, but not as a market price. These weighted PPA prices are listed in Table 3 and facilitate comparison of the costs of different technologies, taking into account their respective coverage rates.

		Solar PV	**Onshore wind**	**Offshore wind**
PPA prices in €/MWh (real 2020)		40.53	43.54	45.63
Coverage rates	**Base load**	40 %	65 %	69 %
	Continuous Commercial ops	42 %	66 %	70 %
	Household	44 %	63 %	67 %
Weighted PPA price in €/MWh (real 2020)	**Base load**	100.82	66.94	66.48
	Continuous Commercial ops	96.52	66.01	65.42
	Household	91.41	69.61	68.25

Table 3: PPA prices, coverage rates and resulting weighted PPA prices for different load profiles

As the table shows, weighting the PPA prices alters the ranking of the technologies assessed. Under the weighted pricing scheme, photovoltaics has the highest PPA price due to its lower coverage rate across all three load profiles. Under the unweighted scheme, offshore wind is the most expensive technology, costing around €5.00 more than photovoltaics; under the weighted scheme, photovoltaics is up to €34.00 more expensive than offshore wind. Onshore and offshore wind differ by a maximum of just € 1.37 across all three load profiles in the weighted scheme. Weighting PPA prices makes it possible to make a more realistic assessment of which technologies offer the best price-performance ratio when hourly rather than annual coverage is taken into account.

This analysis shows clearly that annual GOOs impact negatively on consumers: settling GOOs on an annual basis presents photovoltaics as the most affordable way to meet consumer demand for renewable energy, when it is in fact significantly more expensive than both onshore and offshore wind when its hourly coverage rate is taken into account.

5 GRANULAR GUARANTEES OF ORIGIN AS A FLEXIBILITY INCENTIVE

5.1 Development of the hourly share of renewables over the course of the year

In Chapter 4, we showed that none of the renewable technologies assessed are capable of providing sufficient hourly coverage to meet demand. Current coverage rates can be improved by adapting existing technologies, for example by optimising the orientation and placement of renewables and increasing demand flexibility. New technologies such as storage solutions and hydrogen electrolysers can also provide flexibility.

In this chapter, we wish to show how the price signal sent by granular Guarantees of Origin (GOOs) can facilitate the uptake of flexibility solutions and help to overcome the problem outlined in the previous chapter. The price of GOOs is largely determined by the share of renewables in electricity generation: In hours in which the share of renewables is lower, high demand for GOOs coincides with a low supply. This results in upward price pressure. A low share of renewables signals a constrained market situation in relation to demand for GOOs and is therefore a better indicator of high Guarantee of Origin prices than, for example, the absolute level of demand not met by renewables (the so-called "residual load").

In order to identify the hours with a low share of renewables (hereafter referred to as "critical hours"), we first determine the share of renewables in electricity generation in Germany on an hourly basis for the years 2025, 2030 and 2035. These years were selected as they mark important milestones on the pathway to climate neutrality. Identifying the critical hours will enable us to quantify the hours in which GOOs can be expected to price higher, creating an incentive for flexibility gains.

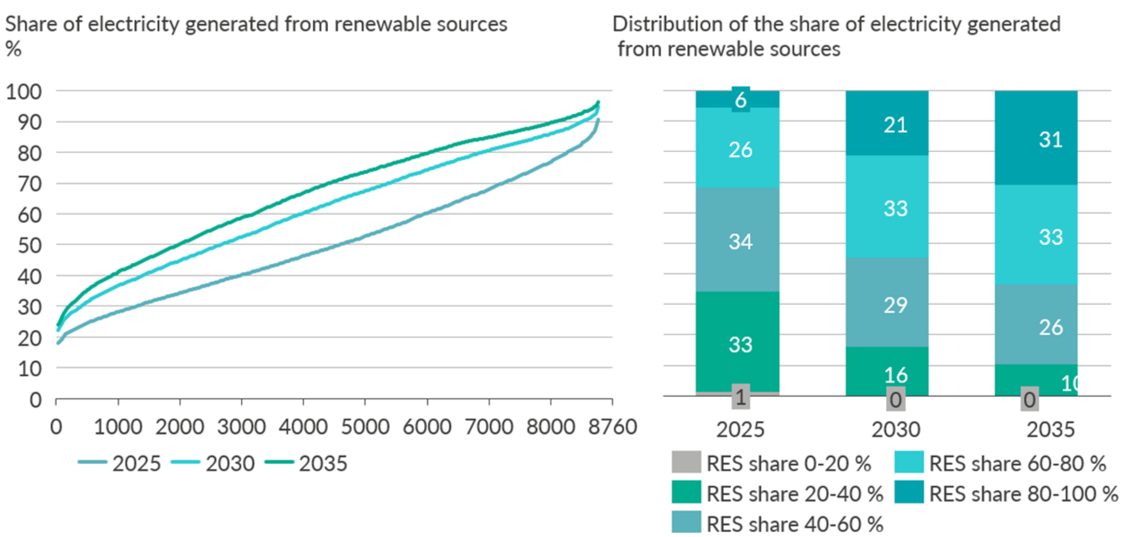


Figure 8: Share of renewable electricity generated for the years 2025, 2030 and 2035 in the Aurora Central Scenario (October 2021); Distribution of the share of renewable electricity generated from renewable sources for the years 2025, 2030 and 2035 in the Aurora Central Scenario (October 2021, Aurora 2021a)

Figure 8 shows the share of renewable energy generated for the years 2025, 2030, and 2035 in the Aurora Central Scenario. Both the minimum and maximum share of renewables increase from 2025 to 2035. The share of renewable energies increases over the years, as shown by the upward trend in the curve.

The distribution of the share of renewable energies in electricity generation can be derived from the figure for these years and is shown in the chart at right in increments of 20 %. In order to identify and evaluate flexibility incentives, we assess the share of critical hours in 2025, 2030, and 2035. Critical hours are hours in which the share of renewable energies in electricity generation is low. We define this as hours in which the share of renewable energy is below 40 %.

This definition is determined to a strong degree by end consumer demand for renewables. The higher the demand from industry and end consumers for green electricity tariffs that actually meet demand, the higher the share of renewable energies required to meet this demand. The growing demand for PPAs in Germany, which we calculate to reach 131 TWh by 2030, is a strong indicator for the assumption that demand for green electricity will increase. It can therefore be plausibly assumed that hours in which the share of renewables falls below 40 % should be treated as critical hours for the years 2025, 2030, and 2035.

Prices for GOOs will trend higher in these critical hours, driven by the low share of renewables, setting incentives for increased production- and demand-side flexibility. As shown in Figure 8, in the Central Scenario 34 % of the hours will still be critical hours in 2025 (i.e., the share of renewable energies will lie in the 0 - 40 % range). The share of critical hours will fall to 10 % by 2035. In contrast, the share of hours with 80 - 100 % renewables increases from 6 % to 31 % in this period. The overall share of renewable energies increases, as does the share of hours with a high share of renewables. Despite this, it is evident that the share of critical hours in which renewables represent only a small share of the supply will still be significant in 2030 and 2035. In addition, we must assume that demand for hourly green electricity tariffs will grow parallel to the share of renewables. Growth in supply will then be matched by increased demand.

The remaining need for flexibility can be met by improving the alignment of consumption and production with the share of renewables or by utilising storage solutions to ‘shift’ green electricity from hours with a high share of renewables to hours with a low share. The price signal sent by GOOs can play an important role in this process, in addition to the price signal of the wholesale market. On the wholesale market, the mix of renewable and dispatchable technologies leads to high price volatility, due to significant differences in the marginal costs of the price-setting technology. We also anticipate greater price volatility in GOOs as a consequence of increased demand for granular GOOs and the resulting price spikes in hours when the share of renewables is lower. Price volatility and price spikes can generate additional revenue for renewables and flexibility through GOOs. This would promote the market-based expansion of renewable energies.

The twin price signals of the wholesale market and GOOs create an incentive to align flexibility options (i.e., price responsive demand and storage solutions) with hours with a high share of renewable energy. In the wholesale market, price volatility is driven not exclusively by renewables, but also by fossil-fuelled must-run-capacity, for example. Since flexibility technologies are geared towards price differences rather than to specific generation technologies, operators may choose to charge storage solutions in hours of high fossil generation (e.g., at night when demand is low and coal-fired electricity generation is high). The twin price signals of the wholesale market and granular GOOs would create an incentive to charge storage solutions when electricity from renewables is abundant. This would increase the profitability of flexible business models and set an incentive to align flexibility with renewables.

Overall, improving the granularity of GOOs sets an incentive for increased flexibility: Hours when the share of renewable energy is particularly low are attractive for flexibility, as the price for GOOs is likely to be higher at these times.

Sensitivity analysis

The calculations above were performed on the basis of the Aurora Central Scenario. This scenario is based on what we consider to be the most likely assumptions regarding future developments. It reflects current (adopted and/or implemented) policy pathways, but not all policy objectives. Key policies necessary to full achieve these goals are still lacking. In addition to this, various regulatory, technical and societal factors will make it difficult to fully realise these ambitions within the proposed time horizons. We have taken these uncertainties into account in order to make predictions that are as realistic as possible. The coalition agreement has set new policy targets, including increasing the share of renewables in the power system to 80% by 2030 The ambitious goals set out in the coalition agreement are not taken into account in our forecast based on the Central Scenario.

In a next step, we conducted a sensitivity analysis in order to assess the compatibility of the core findings of this chapter with an accelerated expansion of renewables. For this analysis, we repeated our calculations on the basis of a second scenario: Aurora Net Zero. Net Zero describes a scenario in which Germany achieves the 2030 emissions reductions targets of the German Climate Action Plan and reaches net zero emissions by 2045. In this scenario electricity demand in 2030 is approximately 78 TWh higher than in the Aurora Central Scenario. This is due to the increased electrification of the heat and transport sectors as well as an increase in capacities for hydrogen electrolysers (hydrogen demand is 53 TWh higher in the Net Zero Scenario in 2030 than in the Central Scenario).

As shown in Figure 9, Aurora Net Zero lies within the target corridor for gross electricity demand (680-750 TWh) established by the new German government in its coalition agreement.

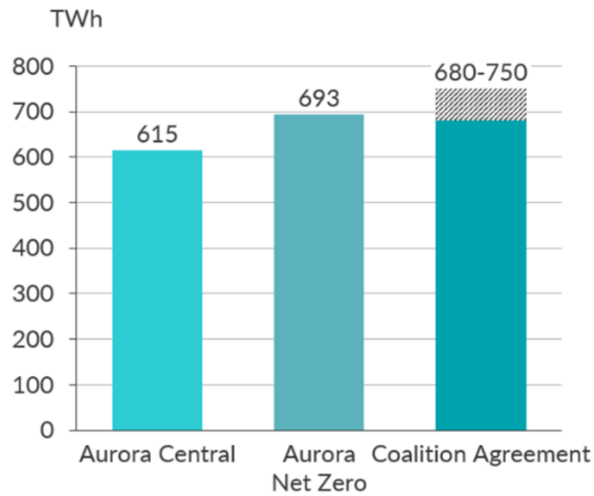


Figure 9: Electricity demand for the year 2030 for the Aurora Central and Net Zero scenarios as well as demand estimated in the coalition agreement (Aurora Energy Research 2021a, SPD, Bündnis 90/Die Grünen, FDP, 2021)

In a next step, we again calculated the distribution of the share of renewable energies under the Net Zero Scenario. The results are shown in Figure 10. An examination of the distribution of the share of renewable energies in this scenario reveals that the number of hours with a high share of renewables increases under Aurora Net Zero. However, there are still critical hours when the share of renewable energies remains low. This shows that even in a scenario with a high share of renewable electricity, we can expect to find price volatility and price spikes for GOOs that will incentivise flexibility.

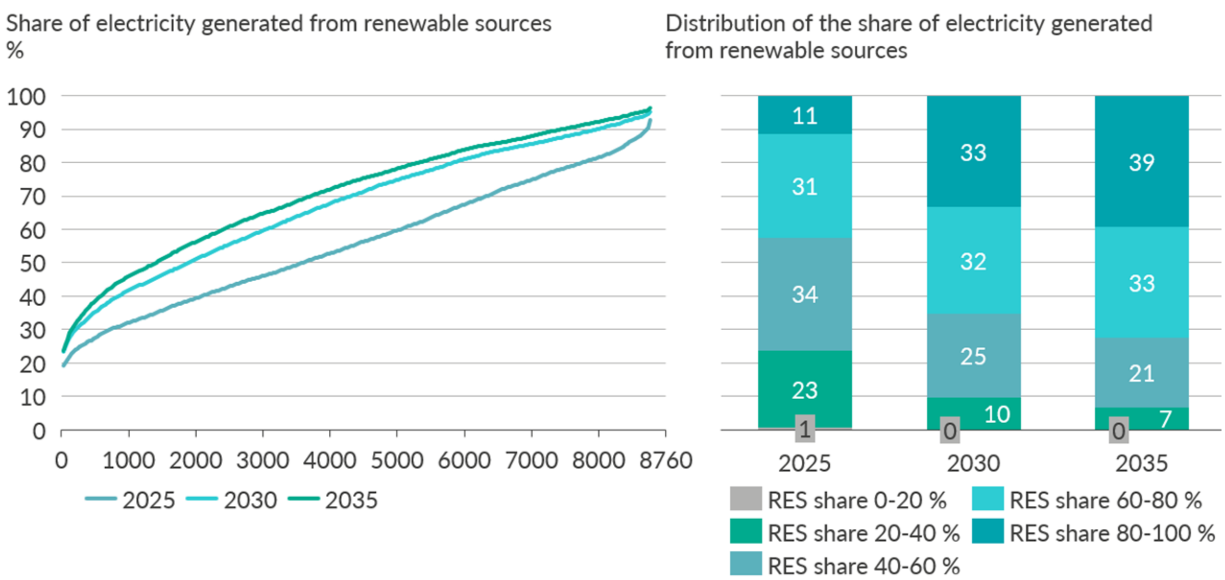


Figure 10: Share of electricity generated from renewable sources for the years 2025, 2030 and 2035 in the Aurora Net Zero Scenario (October 2021; Distribution of the share of electricity generated from renewable sources for the years 2025, 2030 and 2035 in the Aurora Net Zero Scenario (October 2021, Aurora 2021a)

In both scenarios, a supply gap remains: Renewable electricity cannot entirely match demand at all times. In order to meet demand for 100% renewables based on hourly GOOs, more flexibility will need to be built into the energy system. This problem can therefore be best described as a "flexibility gap".

5.2 The price signal as a flexibility incentive

To quantify the flexibility gap, we calculated the average residual load in the 10 % of hours with the lowest share of renewables for both the Central and Net Zero scenarios for the years 2025, 2030, and 2035. The residual load is the share of electricity production that renewables cannot cover due to their volatility. In other words, this is the remaining demand for electricity, most of which must be covered by conventional power plants etc. In Figure 11, the average residual loads are depicted as columns and the corresponding average share of renewables in these hours as lines. As this figure shows, the residual loads for the Net Zero Scenario are lower on average than for the Central Scenario. This is in line with the above-noted finding that the share of renewables is higher in the Net Zero Scenario. The maximum values of the residual load for each year and scenario are also identified in the figure (X). The annual maximum residual load is higher in the Net Zero Scenario than in the Aurora Central Scenario. This is due to the aforementioned higher demand in the Net Zero Scenario, which intersects with reduced conventional capacities from coal and gas-fired power plants. Imports provide an important flexibility mechanism for covering residual load requirements and allow for balancing effects; however, they cannot completely close the flexibility gap. This is because of the weather correlation between European countries, resulting in a high degree of simultaneity in renewable electricity generation.

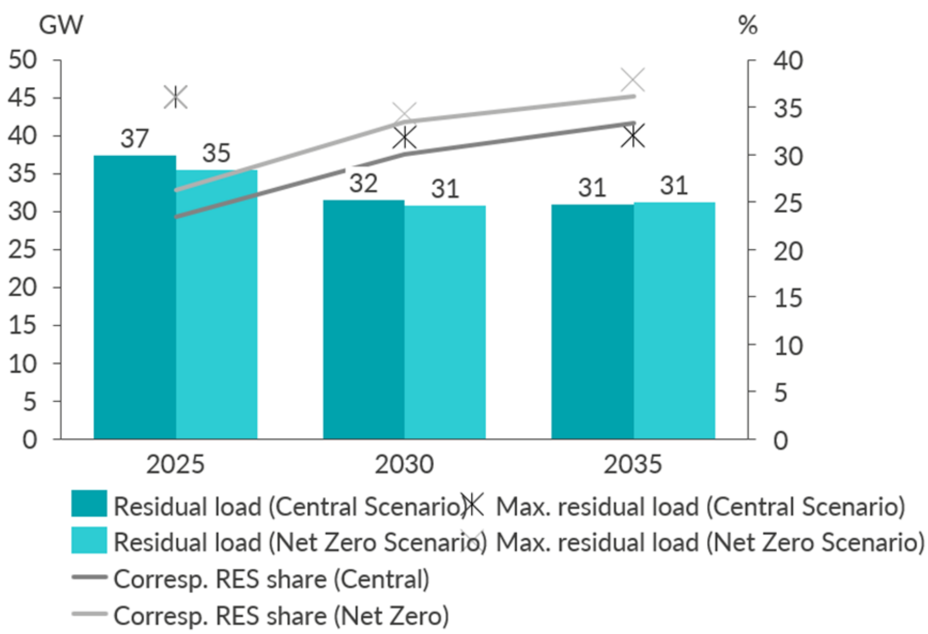


Figure 11: Average residual load in the 10 % of hours with the lowest share of renewables, including the corresponding average share of renewables for the Aurora Central and Net Zero scenarios. Also shown is the maximum residual load that occurred in each scenario. (Aurora Energy Research 2021a)

In order to gain a better understanding of the flexibility gap and flexibility incentives, we examine the share of renewable energy on an average summer and winter day under the Aurora Central Scenario in 2035, as depicted in Figure 12.

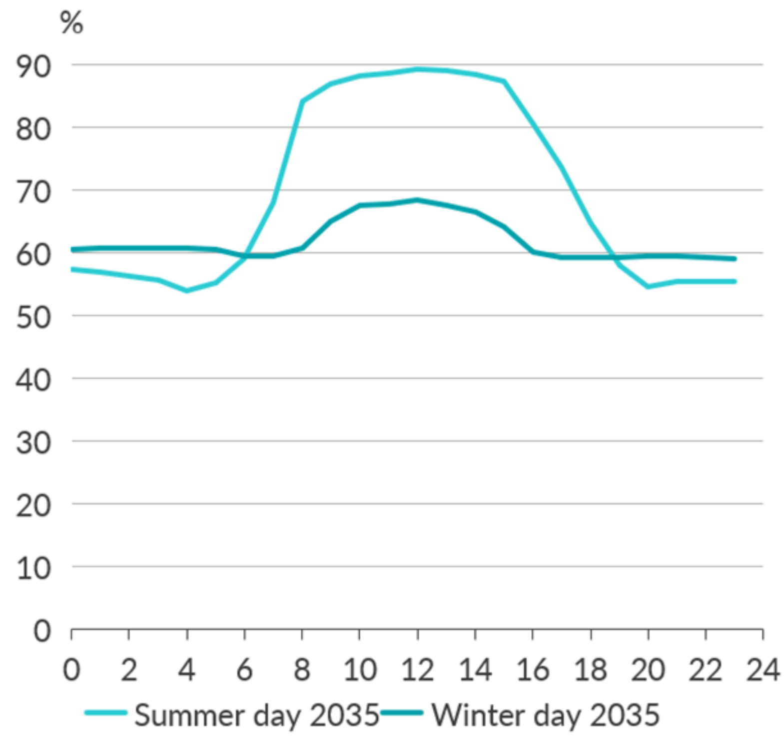


Figure 12: Average share of renewable electricity in summer and winter over the course of the day under the Aurora Central Scenario in 2035 (Aurora Energy Research 2021a)

As the figure shows, significantly higher shares of renewable energies are achieved in summer than in winter, especially during summertime daylight hours (6:00 am - 8:00 pm), reaching a daytime peak of 89 %. At night, the share of renewables drops to an average of 55 % in the summer months. In winter, on the other hand, the share drops to 59 % at night and reaches a daytime peak of 68 %. Overall, the share of renewables is less volatile in winter than it is in summer. The clear discrepancy in performance between summer and winter days suggests that the winter months contribute significantly to the hours with a low share of renewables.

These fluctuations translate into flexibility incentives of varying degrees of granularity. Near-term flexibility is incentivised shifts in hourly electricity pricing throughout the day. However, the share of renewables is also subject to weekly and seasonal fluctuations, which also impact the pricing of Guarantees of Origin (GOOs). These variations in pricing set incentives for medium- and long-term flexibility.

Hours in which the share of renewable energy is particularly low are attractive for flexibility, as the price for GOOs will predictably trend higher at these times. This creates an incentive to ramp up production or reduce demand in hours with high prices and to produce less or demand more in low price hours. Energy storage solutions can be used to store and discharge electricity in response to price changes, ensuring the availability of green electricity in the grid throughout the day. Different technologies can be used to provide flexibility.

- Optimising the orientation of renewables (for example, facing PV arrays east/west rather than south) would enable operators to better align feed-in times with the price dynamics of GOOs. East/west facing arrays produce more electricity in the morning and evening hours. This improves system integration by increasing output in those hours when PV coverage is generally low.
- Improving demand-side flexibility is also incentivised. The additional price signal sent by hourly GOOs would make it more attractive for industry and manufacturers to consume more electricity in hours with a high share of renewables by shifting peak production hours and reducing production in hours with a low share. Compared to annual GOOs, this creates an incentive to align demand specifically with electricity supplied under the PPA, further facilitating system integration.
- Granular GOOs also set incentives for the use of storage solutions for renewables. Price volatility can provide an incentive to charge local storage solutions in hours with a high share of renewables and to feed this electricity into the grid (on an hourly level) at night when solar and wind resources are reduced, for example. Granular GOOs also set an incentive for operation of long-term storage solutions, which can store renewable energy generated in the summer and discharge it in the winter months when coverage is lower.
- A granular price signal would also provide an incentive to hydrogen producers to ramp up the output of green hydrogen electrolysers in hours when the share of renewable energies in the system is particularly high.

The variety of available flexibility solutions highlights a particular strength of the price signal set by GOOs: It is technology neutral. As a market-based price signal, it promotes competitive innovation. When a low share of renewables creates a need for increased flexibility, for example, the price signal will reflect this. The technology that can provide flexibility most efficiently will then respond to the price signal. This market solution ensures that the most affordable flexibility technologies are used and to the extent necessary. This is an advantage over regulatory solutions, which do not have a perfect view of flexibility costs or the scale of flexibility required, and therefore cannot provide the most efficient and economic solution.

An hourly price signal sets short-, medium- and long-term flexibility incentives. This changes the calculation for potential investors and fosters early investment in innovations that would not be worthwhile today without the price signal of GOOs. At the same time, the cost development and learning curves for new technologies are accelerated as a result.

6 RECOMMENDATIONS FOR A GRANULAR MARKET DESIGN FOR GUARANTEES OF ORIGIN

As market-based instruments, Guarantees of Origin (GOOs) can ease the transition to a climate neutral society by promoting the growth of renewable energies. An efficient market design for GOOs is therefore an important building block for a market-based energy transition and the achievement of climate targets.

Our analysis shows that granular GOOs would send a price signal that sets important incentives to increase flexibility, thereby enhancing the system integration of renewable energies and supporting a market-based expansion of renewable generation capacity. As shown in the EPICO KlimaInnovation study on the development of a climate neutral electricity system in Germany, renewable energy capacities can be expanded further without state support over the longer term provided that sufficient private sector financial guarantees are available. The continued utilisation of more expensive alternative generation technologies is also expected to ensure that wholesale electricity prices remain stable, safeguarding the prospects for future revenues from renewables (EPICO 2021b). As another source of revenue, GOOs can also support the market-led expansion of renewables.

Several measures are necessary to harness the benefits of a granular design of GOOs:

1. **Guarantees of Origin should be matched to production on an hourly rather than annual basis.**
   An hourly design currently offers the optimal level of granularity as a trade-off between incentive effects and transaction costs. A granular design improves the alignment of GOOs with real-world consumption, strengthens their price signal, and enhances transparency for end consumers. It also counteracts accusations of *greenwashing*. Implementing this upgrade at European level would both strengthen the liquidity of the European market for GOOs and support the broader energy transition in Europe. In order to implement this change, the European Renewable Energy Directive must be amended and implemented under Germany's Renewable Energy Act and in the relevant implementing regulation stipulating the requirement for hourly granularity.

2. **The granular market design for Guarantees of Origin, and the trading system in particular, must be fundamentally aligned with the desired incentive effects**
   The parameters established in the market design will have a significant impact on the efficiency of the solution. Although an hourly level of granularity is optimal, this could drive up transaction costs for companies, for example, if they were required to track their ownership of GOOs in real time and match hourly consumption to hourly GOOs. The use of GOOs should therefore be verified at intervals greater than the granularity applied to the GOOs themselves. This approach has already been implemented in France, where users are required to match monthly consumption and GOOs on an annual basis. The development of exchange-based auctions will also contribute to the development of the GOO market by providing price transparency. Unlike bilateral trading, exchange-based auctions provide a public price signal for each delivery period. This bundles liquidity and reduces transaction costs through standardisation while also

enabling stakeholders to gain a clearer picture of the market situation and contributing to market development.

One implementation option would be to gradually shift from the annual settlement scheme to a monthly and, eventually, hourly settlement of GOOs. This would afford market actors sufficient time to implement changes. In a next step towards bringing GOOs and physical electricity closer together, policymakers could consider the development of mechanisms that factor the availability of cross-border interconnection capacities into GO trades. This would ensure that renewable electricity can actually be transferred from one country to another.

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