Co-funded by the European Union's
Horizon 2020 research and innovation
programme
under Grant Agreement no. 691797

STORE&GO

Innovative large-scale energy storage technologies and Power-to-Gas concepts after optimisation

D8.2

Report on the acceptance and future acceptability of certificate-based green gases

Due Date	30 April 2018 (M26)
Deliverable Number	D8.2
WP Number	WP8
Responsible	Catrinus Jepma, University of Groningen
Author(s)	D. Hulshof, C. Jepma, M. Mulder
Reviewer	Helge Föcker, Uniper
Status	Started / Draft / Consolidated / **Review** / Approved / Submitted / Accepted by the EC / Rework

Dissemination level

✘	**PU**	Public
	PP	Restricted to other programme participants (including the Commission Services)
	RE	Restricted to a group specified by the consortium (including the Commission Services)
	CO	Confidential, only for members of the consortium (including the Commission Services)

Document history

Version	Date	Author	Description
1.0	2018-02-28	DH, CJ, MM	First draft
2.0	2018-03-23	DH, CJ, MM	Second draft
3.0	2018-05-14	DH, CJ, MM	Third draft

Table of Contents

Executive Summary

Like in virtually all energy markets, consumers face an inherent informational disadvantage regarding the renewable character (and other attributes) in the market for renewable methane. This information asymmetry problem arises from the impossibility to distinguish renewable types of methane from their non-renewable counterparts. This can result in failing markets for renewable methane in the form of adverse selection: consumers may be willing to buy renewable methane (at premiums) but end up buying less or none at all because they cannot credibly buy them. As a result, the size of voluntary contributions of consumers to mitigate climate change by purchasing renewable methane is reduced when this occurs.

Certification schemes have been introduced to address the problem of information asymmetry in energy markets. These certificates, which are administered by an independent third-party organization, provide information about unobservable characteristics to consumers. Certification schemes have particularly developed in electricity markets in the past two decades in Europe. For other energy types, such as renewable gas and hydrogen, certification schemes are much less developed. However, at expected increased volumes of these energy types, the relevance of certification for these markets increases. Despite the presence of certificates for some time, it is unclear to what extent certificate markets are functioning properly and provide a means to trade renewable energy in a reliable way. Moreover, the optimal design of certification schemes for energy goods is not fully understood. Currently, while there sometimes exists a common EU-framework (for renewable-electricity certificates), countries make very different design choices for their respective certification schemes. In particular, schemes differ in the choice of a private or public third-party certifier and in whether the certificate adheres to an international standard or not. It is ambiguous what the best choices are to reduce information asymmetry and prevent adverse selection.

This deliverable analyses the performance of energy certificate markets over time and relates two design features of certification schemes to market performance. More specific, we analyse if the performance of a certificate system depends on (i) the fact if the certifier is a public or private institution and (ii) the adoption of a common international standard.

We apply our statistical analysis to the market for renewable electricity certificates. While this deliverable is part of the STORE&GO research project, centring around renewable methane, we analyse the renewable electricity certificate market because, in contrast to renewable methane certificate markets, there is a sufficient amount of data available. Moreover, the information asymmetry problem in these two markets is practically identical: consumers cannot distinguish between renewable and non-renewable types based on observable characteristics and this problem is further complicated by the presence of a joint infrastructure for the different types of energy.

We find that certificate markets are still in their infancies. While increasing shares of renewable electricity are certified, suggesting this trade mechanism is becoming increasingly important, certificate markets still suffer from poor market liquidity and high volatility in prices. Moreover, a considerable amount of certificates expires and is never used to claim the consumption of renewable electricity. With respect to design features, choices matter for market performance. Our results imply that private certifiers are associated with lower market volumes while adopting an international standard has a positive effect on certified volumes.

1. Introduction

Public consensus exists regarding the need to reduce worldwide increasing greenhouse gas emissions. Failing to do so may result in climate change associated with significant economic and social damages (e.g. Nordhaus 2006). Acknowledgement by governments of the need to reduce emissions has recently resulted in an international agreement to limit the average temperature increase to 2°C above pre-industrial levels (UN 2015). Realising this ambition requires, amongst others, a sizeable structural economic change from non-renewable to renewable-based energy systems: the energy transition. In addition to traditional policy tools to promote the use of renewable energy such as taxes and subsidies, governments have implemented certification schemes to facilitate consumer choice for renewable energy.

Certificates have been introduced to address the problem of information asymmetry in energy markets. Information asymmetry is typically present in energy markets because consumers cannot credibly distinguish between renewable and non-renewable energy. As a consequence, adverse selection may arise: consumers with a preference for renewables may end up buying less of the preferred product (Akerlof 1970). Information asymmetry arises in energy markets as production tends to occur elsewhere and consumers do not experience differences between renewable and non-renewable energy. The presence of networks in some important energy markets (e.g. electricity and gas) also complicates distinguishing between renewable and non-renewables because all energy in the network mingles. The purpose of certification is to bridge this informational gap. By providing consumers with information about unobservable characteristics related to the production method (e.g. plant type or production location), they are enabled to make better decisions.

A number of papers discuss how reducing information asymmetry by disclosing unobserved environmental characteristics can increase the provision of renewables (Dosi and Moretto 2001, Mattoo and Singh 1994). Another set of papers provides evidence on the basis of stated-preference analyses that consumers care about such unobserved characteristics. Particularly large is the literature about consumers' willingness to pay for renewable electricity (see Sundt and Rehdanz 2015 for a meta-analysis). Using revealed preference methods, other papers show that consumers value the presence of a certificate for energy goods in practice (Roe et al. 2001, Fuerst and McAllister 2011). Another branch of papers questions the reliability of certifiers. Mahenc (2017) and Feddersen and Gilligan (2001) provide theoretical evidence that certifiers may provide dishonest information if they have a different objective than promoting social welfare, such as maximizing profit. Lizzeri (1999) shows that sufficient competition between certifiers leads to reliable certification, even when certifiers are maximizing their profits.

In Europe, several certificate systems have been introduced for energy goods. EU directives 2009/28/EC and 2001/77/EC require member states to develop certificate systems for renewable electricity, called Guarantees of Origin (GO). GO certificates for renewable electricity appear to be quite successful with approximately 42% of European renewable electricity production certified (AIB 2017). The directives lay out a common framework for the design of GO certificate systems but differences remain in the adopted designs of countries. For example, differences exist in whether the certifier is a public or private organization. At the same time, unlike in Europe, certification of renewable electricity in the United States is not organized by the government at all but completely entrusted to private third-party organizations.

While certification of renewable electricity has existed for over two decades, certification for other energy goods is much less developed. Certification of renewable gas is relatively new and less regulation exists for these markets as compared to electricity certificate markets. For gas, certification schemes have recently emerged in Austria, Denmark, Finland, the Netherlands and the UK. Contrary to electricity, no common regulatory framework exists such that these certificate schemes do not adhere to any common standard. This leads to differences in, for example, the tracing method of renewable gas production. It is apparent that countries make very different choices regarding the design of certificate schemes while these schemes share the same purpose of reducing information asymmetry.

The in-development technology power-to-gas is a potential contributor to rising volumes of renewable gas in the future. This deliverable is written as part of the STORE&GO research project which investigates the feasibility and (amongst others) potential economic barriers of diffusion of the power-to-gas technology. Certification of renewable gas is such an issue considering that a functioning certificate system enables reaping the willingness-to-pay of consumers for the renewable character. This deliverable evaluates acceptance and future acceptability of certificate-based green gases by evaluating the performance and relation between certificate system design and performance for the renewable electricity certificate market. Our analysis is applied to the market for renewable electricity because there is a lack of data for markets for renewable methane. In contrast, there is much more data available for the market renewable electricity certificates. Because the problem of information asymmetry is equal in these two markets, a great deal can be learned for the proper design of certificate systems for renewable gases from analysing the certificate markets for renewable electricity.

The main question we address in this paper is twofold: (i) how do European markets for energy certificates perform, and (ii) how do design features of certificate systems relate to the performance of certificate markets. More specific, does it matter for the performance of a certificate system if the certifier is a public or private institution and if the system is designed to adhere to a common international standard. This paper contributes to the literature by providing an empirical assessment of the performance of certificates for energy goods in government-created markets. While other papers have generally focussed on a single market in one country (e.g. Roe et al. 2001, Fuerst and McAllister 2011), we analyse GO markets in twenty European countries, which are comparable but differ in some critical design aspects, such as the public/private nature of the certifier.

The functioning and performance of certificate markets is particularly relevant considering the increased volumes of other renewable energy goods such as gas and hydrogen which are expected. At current, in contrast to renewable electricity, these markets are in their very infancy. Properly functioning certificate markets are important to governments and the producers and consumers of renewables. To producers of renewables, the certificate enables reaping higher a higher market price as compared to non-renewable varieties. For consumers with a willingness to pay for renewables, the certificate provides certainty regarding the renewable character and a means to express their willingness to pay for climate protection. To governments, a well-designed certificate can solve the problem of information asymmetry in renewable energy markets. As a result, lower government subsidies may be required to attain similar levels of outputs of renewables, compared to a situation without certification.

This paper analyses the performance of GO certificate markets in twenty European countries over 2001–2016 by assessing a number of market performance indicators. We apply our analysis to the market for electricity GOs considering that, unlike certificate markets for other energy carriers, data is available regarding quantities, prices and trade. Moreover, the electricity GO system is the largest and most ambitious certification scheme for energy goods in Europe. The indicators we assess are the churn rate, price volatility, the share of renewable electricity which is certified and the share of certificates that expires (and is therefore not used to claim the consumption of renewable electricity). We relate the public/private nature and presence of an international standard to the output of certificates, while controlling for other supply and demand fundamentals, using panel data regression techniques.

Our results confirm that certification has become increasingly important in terms of the amount of certified renewable electricity. However, GO markets suffer from very poor liquidity, as measured by the churn rate, and volatile prices. While the churn rate is slowly improving in the EU and most individual countries, we do not observe improvements in volatility over time. Furthermore, GO certificate markets have been in a relatively stable state of oversupply. Overall, certification has become increasingly important as a trade mechanism for renewable electricity but the performance of certificate markets remains poor. With respect to the characteristics, we find that the presence of an international standard significantly contributes to the market volume. Private certifiers are associated with lower market volumes. Facilitating international trade through standardization and public ownership are policies that contribute to a successful certificate market.

The remainder of this paper is organised as follows. Section 2 provides an overview of the literature. Section 3 describes the analytical framework for the analysis. Section 4 describes the data. Sections 5 and 6 provide the results of the market performance and design features-performance analyses respectively. Finally, section 7 concludes.

2. Literature

2.1 Information asymmetry and certificates

Several theoretical papers describe how providing information on the basis of certificates reduce information asymmetry and prevent adverse selection, as described by Akerlof (1970). Dosi and Moretto (2001) and Mattoo and Singh (1994) provide theoretical evidence of the positive effect of information provision on the supply of an environmental-friendly type. Both papers show that an additional (typically undesired) effect of information provision can be an increase in the supply of the environmental-unfriendly type, depending on the circumstances.

With respect to the design of certificate systems, several papers question the reliability of certifiers. Mahenc (2017) and Feddersen and Gilligan (2001) discuss how the incentive of certifiers is related to providing honest information to consumers. In particular, when a certifier's goal deviates from maximizing social welfare, such as maximizing profit (Mahenc 2017) or maximizing environmental quality (Feddersen and Gilligan 2001), the certifier has an incentive to provide dishonest information. When certifiers are profit-maximizing firms, Lizzeri (1999) shows that sufficient competition in certification leads to reliable provision of information.

There exists a broad literature with respect to the valuation by consumers of hidden attributes of energy goods. A first group of these studies applies stated-preference methods to assess preferences for different energy goods and their attributes in a hypothetical buying situation. Particularly for the electricity market, there is substantial evidence that consumers value hidden attributes, particularly, whether electricity is produced renewably (e.g. Bollino 2009; Sundt and Rehdanz 2015 provide a meta-analysis). A second group of studies applies revealed-preference methods to determine the willingness to pay for certified goods with hidden attributes. For example, using hedonic-pricing techniques, Roe et al. (2001) show that the actual premium paid by end-users in the US for renewable electricity significantly increases when it received Green-E certification. More examples of revealed-preference analyses showing that consumers value environmental certification include Fuerst and McAllister (2011) for the US real-estate market and Elofsson et al. (2016) for the Swedish milk market. However, there exists also empirical evidence of certification schemes that leave consumer demand unaffected. Park (2017) finds that the presence of a Korean energy-efficiency certificate does not affect the price of the certified goods. Similarly, Hornibrook et al. (2015) report that an ecolabel scheme of the largest supermarket in the UK containing carbon information did not affect consumer choices.

A last related branch of literature discusses the physical design of certificates and the effect on consumer choice. Newell and Siikamaki (2013) find that, in addition to factual information in energy-efficiency certificates, the presence of logos (e.g. the US Energy Star logo or EU letter grade) significantly increases the WTP of consumers for energy intensive household appliances.

2.2 Certification of renewable methane in Europe

Similar to other energy markets, the market for renewable methane suffers from information asymmetry. In the absence of regulation, renewable methane producers (e.g. owners of anaerobic digesters or power-to-gas plants) will not be able to credibly claim their product is renewable. End-users are not able to distinguish renewable methane from fossil methane based on observable characteristics. This leads to the earlier discussed consequence of adverse selection: end-users that prefer renewable methane (and accordingly have a higher willingness to pay for the renewable type) may buy the non-renewable type (and therefore not express their higher willingness to pay for the renewable type) because they have no means to verify claims about the renewable character of the methane they buy. The typical result of this market failure are lower market volumes and lower market prices.

The discussion on the acceptance and future acceptability of certification for renewable methane very much relates to the discussion on solving the information asymmetry problem in markets for renewable methane. Certification of renewable methane provides a possible solution to the information asymmetry problem that is inherently present. It provides the end-user with certainty about the renewable character and enables producers to reap the additional willingness to pay of end-users for the renewably type. Another possibility to provide certainty regarding the renewable character of methane would be physical delivery via a (newly built) dedicated infrastructure. While this would practically eliminate information asymmetry, this is an unrealistic option. It is improbable that the huge costs of building a dedicated infrastructure outweigh the benefits of eliminating information asymmetry in the market for renewable methane. In contrast, operating a certification scheme is much cheaper as it merely requires a digital infrastructure[1]. As is the case with a dedicated infrastructure, a well-designed certificate scheme for methane provides certainty to end-users about the renewable character, thereby alleviating the information asymmetry problem. In terms of acceptability, end-users fully 'accept' delivery on the basis of certificates if the market outcome approximates the market outcome without information asymmetry[2]. The degree to which certificates reduce information asymmetry, i.e. to which end-users accept certificate-based delivery, depends importantly on the design of the certification scheme. Partly due to the still relatively limited experience with certification schemes that intend to reduce information asymmetry for energy goods, the optimal design of a certification scheme (for renewable methane and other energy goods) remains an open question.

A number of certification schemes for renewable methane have emerged in Europe in recent years. Importantly, this includes Austria, Denmark, Finland, France, Germany, Netherlands, Switzerland and the UK (EBA 2016). In the UK, two systems operate alongside each other. There is no formal alignment between these schemes as implementation is a national affair. This has led to remarkable differences in the designs and standards of these schemes. This is not surprising considering that the optimal design of certification schemes for energy goods is not yet fully understood. Differences are encountered in, for example, the tracing method of the renewable energy, if the certifier is operated by a public or private organization and the presence of restrictions on import and export. Also, the attributes about which the certificate reports widely differ between certificate scheme, i.e. these schemes all have very distinct standards.

Table 1 summarizes several design characteristics of the most important existing renewable methane certification schemes in Europe. Out of nine certification schemes, four are operated by public certifiers whereas five are operated by private certifiers. While in Austria, France and Switzerland these private certifiers hold national monopolies, in the UK some competition is allowed between certifiers given the presence of two active private certifiers. Differences in national standards also arise from different ways of tracking the renewable methane in the system. Two tracking methods are observed: mass balancing and book and claim tracking. In both methods, the certified renewable

---

[1] The costs of a certification scheme importantly include maintaining the digital infrastructure, metering costs at renewable production sites and administrative costs imposed on market participants. As a reference for the first component, the total costs of the Dutch certifier of renewable electricity Certiq were less than €2mln on average since the start of operation (costs in 2016: €2.3mln) (Certiq 2018). Estimates for the other components are not available.

[2] Generally, the market outcome with certification (successfully eliminating information asymmetry) will deviate somewhat vis-a-vis the efficient outcome when information asymmetry is absent because certification is costly and these costs are typically imposed on producers, altering their optimal choices as compared to the no-information asymmetry scenario.

volume is administratively monitored while the certified volume is allowed to mix with the non-certified volumes. The primary difference between the two methods is that under a mass balancing system, a physical link is required in the complete supply chain whereas under a book and claim system there exists no physical link between the certified volume and end-product delivered to the consumer. Effectively, a certificate from a book and claim system can be matched with end-product volumes anywhere in the world (provided the certificate is accepted there) while a certificate from a mass balancing system is always matched with volumes that flow through the supply chain corresponding to the one of the certified physical volume. Under a book and claim system, trade in the physical volume and certificates is fully separated whereas under a mass balancing system trade in certificates and physical volumes is not separated. The advantage of a mass balancing system is that firms can claim to consumers that, *somewhere within the supply chain*, sufficient renewable volume was added, as opposed to a book and claim system where firms can claim that *somewhere* sufficient renewable volume was produced. This is advantageous if consumers care about such a distinction. The disadvantage of a mass balancing scheme are the higher costs of monitoring as compared to a book and claim system (see Mol and Oosterveer (2015) for a general comparison between different tracking methods). For renewable methane certification, some strongly advocate for adopting a European wide mass balancing system (BIOSURF 2016). Interestingly, eight out of nine certification schemes in table 1 have opted for a book and claim system in practice.

The unavailability of data in renewable methane certificate markets prevents us from applying a statistical analysis to analyse the relationship between these design characteristics and the degree to which information asymmetry is resolved. Table 1 also summarizes the data availability for the most important renewable methane certificate schemes. The Austrian certifier is the only certifier that reports data, although they report only issued volume of certificates per month but nothing on cancellation, expiry or domestic and international trade.

While it is difficult to learn about the optimal design of a certification scheme from studying the market for renewable methane certificates due to the unavailability of data, analysing markets for renewable electricity certificates appears much more instructive. The information asymmetry problem is practically identical in the markets for electricity and methane: in both markets, consumers may prefer a renewably produced type but cannot distinguish between types based on observable characteristics. In addition, in both markets, the presence of a network where different types mingle further complicates the information asymmetry problem. Moreover, a number of important fundamental choices about the design of the scheme that have to be made are the same for certification schemes in the two markets. Examples of choices to be made are whether to adopt a national standard or adopt a harmonized international standard and whether to appoint a private or public institution as certifier.

Table 1: Design characteristics of renewable methane certification schemes in Europe

	Operating since	**Nature certifier**	**Tracking method**	**Data reporting**
Austria	2012	Private	Book and claim	Only monthly volume of issued certificates
Denmark	2011	Public	Book and claim	No
Finland	2013	Public	Book and claim	No
France	2012	Private	Book and claim	Unknown
Germany	2010	Public	Mass balancing	No
Netherlands	2009	Public	Book and claim	No
Switzerland	Unknown	Private	Book and claim	No
UK (GGCS)	2011	Private	Book and claim	No
UK (BMCS)	2012	Private	Book and claim	No

Importantly, in contrast to the market for renewable methane certificates, a lot of data is available for markets for renewable electricity certificates. There are more certification schemes in Europe, these schemes have a longer history and, contrasting to renewable methane certifiers at this moment, renewable electricity certifiers report detailed monthly data with respect to issuance, cancellation, expiry, domestic trade and international trade of certificates. For these reasons, we apply our statistical analysis to the renewable electricity certificate market.

2.3 Certification of renewable electricity in Europe

Renewable electricity certificate (GO) markets have emerged since 2001 as EU legislation mandates ach member state[3] to set up a renewable-electricity certification scheme. European GO certificates explicitly target reducing information asymmetry between producers and consumers of renewable electricity. Certification under the GO system is voluntary for producers in all countries except for Switzerland and Austria. Certificates are valid for one year after issuance. In order to prove consumption of renewable electricity, end-users notify the certifier such that certificates are cancelled (or utility companies act on behalf of end-users). If a certificate is not cancelled within one year, it automatically expires forever and hence is not used to prove consumption of renewable electricity.

While the EU legislation requires member states to organize national certification schemes, countries have considerable freedom in choosing their own design. This has led to differences in systems between countries with respect to quality assurance and market organization.

Each country appoints a certifier that is responsible for issuing and cancelling certificates and monitoring trade. More than one certifier may be appointed but each certifier is responsible for a non-overlapping area. As a result, only one monopolistic certifier is active in most countries. Exceptions are Greece and Belgium with respectively three and four certifiers that hold regional instead of national monopolies.

Countries may freely decide to appoint a public or private institution as certifier. By EU legislation, the appointed certifiers are required to be independent from production, trade and supply of electricity. In practice, Switzerland switched from public to private certifier in January 2018, France switched from public to private certifier in March 2013, Czech Republic appointed a private certifier since the start of operation in 2013 and Portugal initially appointed a public certifier but had a private certifier in place from April 2013 – March 2015. The other countries have appointed public certifiers.

With respect to market organization, the EU rules try to foster an integrated European market for certificates. Countries are obliged to accept the import of foreign GOs[4]. At the same time, countries are free to set trade restrictions and two countries have implemented such restrictions: Austria does not allow the export of certificates obtained by a generator that has received state support and Spain requires any revenue from exporting certificates to be transferred to the government, which functions as an export ban.

Several countries do not allow producers to obtain certification at all when they received state support. This concerns Croatia, France, Germany, Ireland and Luxembourg. The typical rationale for this policy is that, as the state support is intended to provide a regular profit, additional revenues from certification would be windfall profits for the producers.

In order to ensure reliable international transfers, a number of countries have adopted a voluntary common standard for certificates, the EECS-standard. Countries trade in these EECS-complying

[3] Norway and Switzerland transposed this European GO legislation into national legislation.
[4] Expected fraud is a valid reason to deny imports of certificates from a country.

certificates through a central electronic hub which is operated by the Association of Issuing Bodies (AIB), an association of the national certifiers which is also responsible for formulating the international EECS standard. The presence of a standard facilitates trade through regular advantages of standardization: it establishes a quality level of certificates and eases comparing certificates from different countries. The presence of a central hub acts to reduce transaction costs. Without a central hub, each country would set their own procedures for import and export. Moreover, a central hub fosters reliability in international transfers as only the central hub's operator has to be verified on reliability rather than the reliability of the operators of each individual country. Considering that an international transaction is merely a transfer of electronic data, the presence of a central electronic hub reduces the possibility of fraud.

Error! Reference source not found. summarizes the design choices of the countries we analyse. I n addition to the presence of the international standard and the certifier's public/private character, this table reports if a country has export and/or certification restrictions in place.

Trade in guarantees of origin occurs only bilaterally or via brokers at current. Certificates are differentiated by a large number of characteristics. As a result many different 'types' of certificates exist. This does not facilitate exchange trading. Nevertheless, the German exchange EEX facilitated trading in three GO products since 2013 but trading has been seized in December 2017 because of a lack of liquidity on the exchange.

A note on the limited market transparency appears appropriate. European energy regulators have been occupied with promoting transparency on energy markets as this would improve market efficiency (e.g. ACER 2016). While the certificate market for electricity is the most developed in Europe, as compared to certificate markets for other energy carriers, the available market information is limited. Quantity data is publicly available through the AIB for all European countries. Unfortunately, the

Table 2: Design characteristics of national GO certification schemes.

	Introduction international standard	**Nature certifier**	**Export restrictions**	**Certification restrictions**
Austria	2004	Public	Yes	No
Belgium	2006	Public	No	No
Cyprus	2014	Public	No	No
Croatia	2014	Public	No	Yes
Czech Republic	2013	Private (2013-current)	No	No
Denmark	2004	Public	No	No
Estonia	2010	Public	No	No
Finland	2001	Public	No	No
France	2013	Private (2013-current)	No	Yes
Germany	2013	Public	No	Yes
Iceland	2011	Public	No	No
Ireland	2015	Public	No	Yes
Italy	2013	Public	No	No
Luxembourg	2009	Public	No	Yes
Netherlands	2004	Public	No	No
Norway	2006	Public	No	No
Portugal	-	Private (2013-2015)	No	No
Spain	2016	Public	Yes	No
Sweden	2006	Public	No	No
Switzerland	2009	Private (2018-current)	No	No

quality of the data is not flawless. We came across several indications of flaws such as illogical reporting and incomplete reporting. Since certification is principally a tool to reduce information asymmetry and thereby facilitate reliable trading, reliable and transparent certification data is a key requirement for a successful certificate system. Transparency and reliability by certifiers reflect that they are correctly executing their task. With respect to price data, there is no data available in the public domain.

3. Analytical framework

We assess the performance of certificate markets by assessing four markets indicators (section 3.1): the share of renewable electricity with a certificate (the certification rate), the churn rate, price volatility and the share of certificates that expires (the expiration rate). We relate design features of certification schemes to the performance by estimating a reduced form model based on quantities and two design variables, indicating the private nature of the certifier and the presence of a voluntary common standard, while controlling for other supply and demand factors (section 3.2).

3.1 Market performance

To assess the functioning of certificate markets, we analyse four performance indicators over time which relate to primary market outcomes such as quantities, prices and trade.

Firstly, we assess the certification rate. Generally, maturing markets are associated with increasing output volumes. As the amount of certification is related to the amount of renewable electricity (which has recently been rapidly increasing in many countries) we analyse the share of certified renewable electricity instead of the absolute volume. The certification rate cr is calculated as:

$$cr_{ti} = \frac{Q_{ti}}{RE_{ti}} \quad (1),$$

where Q refers to the volume of issued certificates and t and i refer to time and country.

Secondly, we assess market liquidity by evaluating the churn rate. The churn rate is frequently used as an indicator for liquidity in physical and financial markets (e.g. Heather 2015; ACER/CEER 2017). It indicates how often a product is traded before it is used/consumed. The churn rate may be defined as the ratio of total traded volume to the total final consumption volume. A higher churn rate indicates a higher level of market liquidity. For commodity markets, a threshold for the churn rate above which a market generally is considered mature is 10 (Ofgem 2009).

We construct three different churn rates in order to cope with the unavailability of individual transaction data. Our dataset only includes aggregated data for the number of issued, cancelled, domestically transferred, imported and exported certificates in a given calendar year[5]. As certificates have a lifespan of one year, virtually every certificate issued in a given calendar year could be cancelled in the next calendar year. Similarly, many transactions in the previous calendar year may relate to certificates that are cancelled in the current calendar year. In our aggregated data, transactions in a given calendar year can thus relate to certificates issued in the previous year or to certificates which were cancelled in the next year. The same goes for imports. Imports in one year may be cancellable in the next calendar year. In an attempt to overcome this difficulty, we constructed three indicators for the churn rate that differ in how final demand for consumption is calculated. The first churn rate is based on the domestically traded volume and the number of issued and imported certificates in the same calendar year. The number of issued and imported certificates jointly determine the tradable volume in a market. For individual countries, the first churn rate is given by:

[5] Data for issuance, cancellation and expiration of certificates by the AIB is provided twice: (i) by the time of production and (ii) by the time of transaction. Data provided by the time of production (i) refers to when the electricity related to the certificate was produced while (ii) refers to when the actual transaction took place, i.e. the year a certificate was issued. Discrepancies arise due to the administrative processing time of certifiers. As a result, renewable electricity produced in year t may receive a certificate in year t+1. Availability of data differs between the two statistics. E.g. data for issuance and expiration of certificates by time of transaction does not exist prior to 2009 while it is available for all years by time of production.

$$x_{ti}^{1} = \frac{T_{ti}}{Q_{ti}+IM_{ti}} \qquad (2),$$

where $x_{t,i}^{1}$ is churn rate 1, T is domestic transfers and IM is imported certificates.

The second churn rate is based on current year's traded volume and the number of issued and imported certificates in the previous calendar year:

$$x_{ti}^{2} = \frac{T_{t-1,i}}{Q_{t-1,i}+IM_{t-1,i}} \qquad (3).$$

The third churn rate is based on the total traded volume and the total number of cancelled certificates in the same calendar year:

$$x_{ti}^{3} = \frac{T_{ti}}{C_{ti}} \qquad (4),$$

where C refers to the volume of cancelled certificates.

The first churn rate relates current trade to current production, the second relates current trade to previous production and the third relates current trade to current consumption. There appears to be no good reason to prefer one over the others with our dataset. Therefore, we will report the churn rate for individual countries based on the simple average of these three churn rates:

$$xr_{ti} = \frac{x_{ti}^{1}+x_{ti}^{2}+x_{ti}^{3}}{3} \qquad (5).$$

For the whole region, we cannot use (2), (3) and (4) to calculate the churn rate. This is because, for all countries combined, imports/exports are equal to zero since all registered imports and exports are between countries within the GO scheme. Therefore, if we consider the whole region, imports/exports should be regarded as transactions. Available volume for final consumption is simply aggregated issued or cancelled volume. To take this into account for the whole region (indicated by the prime symbol), we calculate slight variations on (2), (3) and (4) which are again based on issuance, previous year's issuance and cancellations respectively:

$$x_{t}^{1\prime} = \frac{\sum_{i=1}^{n} T_{ti} + \sum_{i=1}^{n} IM_{ti}}{\sum_{i=1}^{n} Q_{ti}} \qquad (2'),$$

$$x_{t}^{2\prime} = \frac{\sum_{i=1}^{n} T_{t-1,i} + \sum_{i=1}^{n} IM_{t-1,i}}{\sum_{i=1}^{n} Q_{t-1,i}} \qquad (3'),$$

and

$$x_{t}^{3\prime} = \frac{\sum_{i=1}^{n} T_{ti} + \sum_{i=1}^{n} IM_{ti}}{\sum_{i=1}^{n} C_{ti}} \qquad (4').$$

We report again on the basis of the simple average of these three:

$$xr_{t}' = \frac{x_{i}^{1\prime}+x_{i}^{2\prime}+x_{i}^{3\prime}}{3} \qquad (5').$$

We cannot compare this churn rate to the churn rate of individual countries as (5') will tend to be higher than (5). This is inherent to increasing the geographical span of the market such that imports/exports become part of traded volume instead of the available volume for consumption (increasing the numerator and decreasing the denominator). To calculate a churn rate for the whole region which is comparable to the churn rate for individual countries, we take the cancelled-volume-weighted average of (5):

$$xr_t'' = \frac{\sum_i^n xr_{ti} * C_{ti}}{\sum_i^n C_{ti}} \quad (6).$$

Thirdly, we assess the development in certificate price volatility. Price volatility is an indicator for fluctuations in the price and hence price uncertainty. Generally, improvements in market maturity and liquidity are associated with decreasing price volatility (ACM 2014). In mature, liquid markets, single events that affect supply and demand (e.g. a power plant outage) are absorbed by the market with less profound price effects as compared to illiquid markets. One common measure of price volatility is calculating the standard deviation of price changes (e.g. Regnier 2007). We calculate annual price volatility as the standard deviation of monthly relative price changes.

Fourthly, we assess the expiration rate. Not every issued certificate is actually used to prove the consumption of renewable electricity. Certificates have a limited lifespan within which they can be used to claim consumption of renewable electricity. If they are not used within this lifespan, they expire and are never used to directly prove the consumption of renewable electricity. A high expiration rate may indicate a low demand for renewable electricity on the basis of a certificate from end-users. We calculate the expiration rate by dividing the number of expired certificates (E) by the number of total issued certificates:

$$er_{ti} = \frac{E_{ti}}{Q_{ti}} \quad (7).$$

We divide by the number of total issued certificates to account for the fact that issuance and expiration are related to each other. Larger values for this indicator are associated with increasing levels of excess supply of certificates.

3.2 Relating certificate design features to market performance

To relate the two design features to market performance, we estimate a reduced-form model of the quantity of issued certificates, which is embedded in our first quantity-related performance indicator. The intuition behind the model is that changes in certified volume over time and between countries are caused by changes in the fundamental demand and supply factors. The quantities of issued certificates we observe reflect the points where the demand and supply curves in the wholesale market intersect. We include two certificate system design characteristics and, after accounting for other fundamentals, test whether they have an effect on the certified volume. We estimate the model $Q_{ti} = \phi(X, Y, Z)$ where X contains the design characteristics and Y and Z the supply and demand variables. We will now first elaborate on these characteristics and fundamentals.

3.2.1 Design characteristics

We include two design features in the model: the presence of a voluntary international standard and the public/private nature of the certifier.

The presence of an international standard, as opposed to a domestic standard, facilitates international trade through reducing transaction costs. With domestic standards, transaction costs may be large or even prohibitive. For example, countries may require imported certificates to undergo a time-consuming and costly verification process. Due to the international standard, transaction costs may be lower, fostering international trade. As a result of more international trade, consumers have a greater number of products to choose from (which is particularly relevant if consumers care about the production location) and competition between producers increases. Overall, because of standardization, the quantity traded in the market increases. Some countries may experience decreases while others experience increases.

The public/private nature of a certifier can be related to market performance through the reliability of certification and the certification fee. Under the assumption that governments are more inclined to maximize social welfare than (profit maximizing) firms, private certifiers have a greater incentive to provide dishonest certification than public certifiers (Mahenc 2017) by certifying grey as green, increasing their revenues. This puts upward pressure on the supply of certificates. However, as Mahenc points out, consumers may reasonably expect this type of behaviour from a profit-maximizing certifier. Consumers may trust a private certifier less, putting downward pressure on their demand. In his framework, unreliable certification only occurs when certifiers are more oriented towards maximizing profit than social welfare. When certification is reliable, certifiers with some private concern may select a higher certification fee, as opposed to certifiers that solely maximize social welfare.

3.2.2 Supply and demand factors

An important factor affecting supply in the certificate market is the output of renewable electricity generators, which in turn largely depends on meteorological factors. The output of these generators is typically eligible for certification such that increases in renewable electricity production directly influence the potential volume that receives certification. The installed capacity of renewable electricity generators determines the maximum output of renewable electricity. Meteorological conditions such as the wind speed, rainfall and solar radiation determine the actual output at a given moment.

Obtaining certification is costly in most countries and these costs are related to the supply of certificates. Higher fees will tend to increase the supply curve. Several types of fees are encountered in practice: no fees, only variable fees, only fixed fees and combinations of variable and fixed fees.

Restriction policies on certification and exports affect the demand for certificates on a wholesale level. Governments that limit certification to non-supported generators put downward pressure on the demand for certification since certification becomes uninteresting when subsidies exceed certificate prices. Export restrictions limit the possibilities to remarket the certificate for a generator, putting downward pressure on expected benefits from certification and demand for certificates in countries where such restrictions are present.

The price of electricity is also expected to be relevant for the certified volume via demand for certificates. The final price of renewable electricity depends on both the certificate price and the general wholesale price of electricity. The certificate price only represents the green premium for renewable electricity as certificates and physical electricity are traded separately. Sellers of renewable electricity need to procure both physical electricity and a certificate. Therefore, increases in the price of electricity raise the final costs of renewable electricity for end-users, putting downward pressure on the demand for renewable electricity and certificates.

Another important demand side variable is the level of income. As income rises, both residential and industrial end-users increase their demand for (renewable) electricity (Kamerschen and Porter 2004). Increases in the use of renewable electricity tend to increase the certified volume as more certificates are required for those end-users with renewable electricity contracts.

3.2.3 Empirical model

We estimate a panel data model of the quantity of issued certificates Q_{ti} in year t in country i as function of supply and demand fundamentals and the two design characteristics. The design characteristics are represented by two dummy variables indicating whether the international standard (ST) is present and the certifier is public or private ($priv$). We include the total renewable-electricity generation (QRE). We also include two supply and demand fundamentals that relate to the general electricity market: the consumer electricity price (PE) and a real GDP index (Y). Finally, we include two certification policy variables: export restrictions (exr) and certification restrictions (cer), which are both time-invariant. The equation we estimate is:

$$Q_{ti} = \alpha_1 + \alpha_2 ST_{ti} + \alpha_3 priv_{ti} + \alpha_4 QRE_{ti} + \alpha_5 Y_{ti} + \alpha_6 PE_{ti} + \alpha_7 exr_i + \alpha_8 cer_i + c_t + u_{ti} \quad (8),$$

where c is an unobserved, time-invariant individual effect and u an error term. Here, c could for example capture differences between countries in preferences for renewable electricity. Sundt and Rehdanz (2015) show that the average willingness to pay for renewable electricity differs between countries. One could well imagine that such preferences are correlated with income (Mozumder et al. 2011) or renewable electricity generation.

The cost of obtaining a certificate is not included in the empirical model as information for individual countries is not available for the majority of periods. The complex cost structures pose another problem to including them in our model (e.g. variable costs that decrease in certified volume, combined with annual fixed fees depending on the size of a generator).

4. Data

For the data analyses we obtain data from various sources for 20 European countries: Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden and Switzerland. Certification data is available from 2001-2016 while availability for other variables is sometimes limited.

Certification data comes from the AIB, which provides annual data on issuance, cancellation, expiration, domestic transfers, imports and exports of GOs. The AIB collects this data from the national certifiers. The certification data on the AIB website is aggregated for all types of electricity, including fossil and nuclear. For our analysis, the AIB has provided separated data for fossil, nuclear and renewable electricity. We almost exclusively use data for renewable electricity in this paper. The earlier mentioned flaws we encountered in the certification data are (i) illogical reporting: Croatia cancelled and expired certificates for the first time in 2013 while the first certificates were issued and imported in 2014; (ii) incomplete reporting: Sweden and Austria issue non-tradeable type of GOs and these are not included in the AIB database; and (iv) mixing of different types of certificates: the database reports one non-zero entry for the UK. Consultation with the AIB learned that this entry concerns RECS certificates instead of GOs. RECS is a private voluntary certification scheme which was administered by the AIB in the past.

We made three initial adaptations to the AIB database. First, we remove Slovenia from the database because data is not reported out of fears of exposing the trading position of one market participant. Second, we remove the UK from the database since the reported activity concerns RECS certificates instead of GOs. Third, we merge the data of the four Belgian certifiers to obtain single observations for Belgium.

Our GO price data comes from Greenfact. Greenfact is a market-monitoring firm which obtains prices by consulting market participants. Our dataset includes monthly volume-weighted average prices for certificates. It further specifies the production year, certificate origin (country or region e.g. ‘Nordic’ or ‘EU’), production technology and the trade volume. Observations range from 2011-2017 but periods for most of the products are (much) shorter. In order to find comparable prices, we define a spot contract as contract with a production year equal to or one year prior to the transaction year. This seems most logical considering that certificates expire after one year. Most of the trades in the database are spot contracts. We further distinguish a product by country of origin and production technology.

From Eurostat, we extract the real annual GDP index and the electricity price for all countries except for Switzerland, which is unavailable. We use the bi-annual household electricity price and take the simple average to find the annual average electricity price. Some years are missing for Croatia, Estonia and Iceland. For Switzerland, we use the average annual end-user price, as reported by the Swiss Federal Office of Energy until 2015. All prices expressed in Swiss Francs are converted into Euros using the annual average CHF/EUR exchange rate, as reported by Eurostat.

We obtain annual data on the production of renewable electricity for EU-countries and Norway from Eurostat (available until 2015). For Switzerland, we obtain this data from the IEA.

When firms implemented the international standard is taken from Fact Sheet 17 on the AIB website. We inspect the websites of the national (former) certifiers to determine whether they are public or private institutions.

Table A.1 in appendix A reports the descriptive statistics, except for the certificate prices, which are reported in table A.2 in appendix A.

5. Market performance

5.1 Certification rate

Certification of renewable electricity has become increasingly important since the start of operation in 2001. Figure 1 shows the development of the certification rate of renewable electricity, fossil electricity and total electricity in all countries combined. While the production volume of renewable electricity increased in the considered period, the amount of certified renewable electricity grew faster. As a result, the certification rate of renewable electricity increased from 0.2% to 35.5% from 2001-2015. In terms of volume, certification has gained considerable importance as mechanism to trade renewable electricity. While the majority of countries also certifies fossil electricity, this is much less important as indicated by the low certification rate of 1.7%.

There are significant differences between countries in the relative importance of certificates. Figure 2 shows the development of the certification rate in individual countries by comparing the average amount of renewable electricity production with a certificate in percentage of renewable electricity production per country between four periods: 2001-2004 with 2005-2008 (panel a), 2005-2008 with 2009-2012 (panel b) and 2009-2012 with 2013-2015 (panel c). Years without active certification are excluded when calculating the averages. Country names are represented by two-letter abbreviations. In these planes, countries on the diagonal lines reflect equal observations for the two considered periods, hence no change in the relative amount of certification. In most countries, the amount of certified renewable electricity increases between two periods or remains stagnant.

In all periods, several countries are located quite distant from the diagonal line and lie above it. These countries experienced a considerable increase in the rate of certification. Certification has become particularly important (>70%) in Denmark, Finland, The Netherlands, Norway and Switzerland. Most other countries experience increases as well.

Only one observation lies somewhat far below the diagonal: Sweden in panel c, which is due to a data issue. Following a change in Swedish legislation, part of Swedish certificates became ineligible for export in December 2010. These export-ineligible certificates are not included in the AIB database. The rest of the observations that lie below the diagonal (4 out of 52) are countries with very low certification rates (<2.5%).

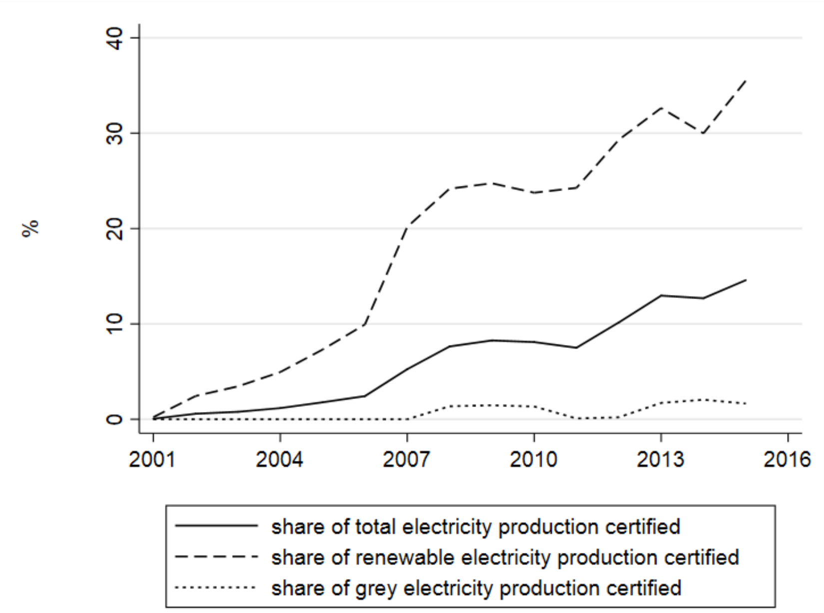

Figure 1: The electricity certification rate in Europe, 2001-2015. Sources: AIB, Eurostat, IEA.

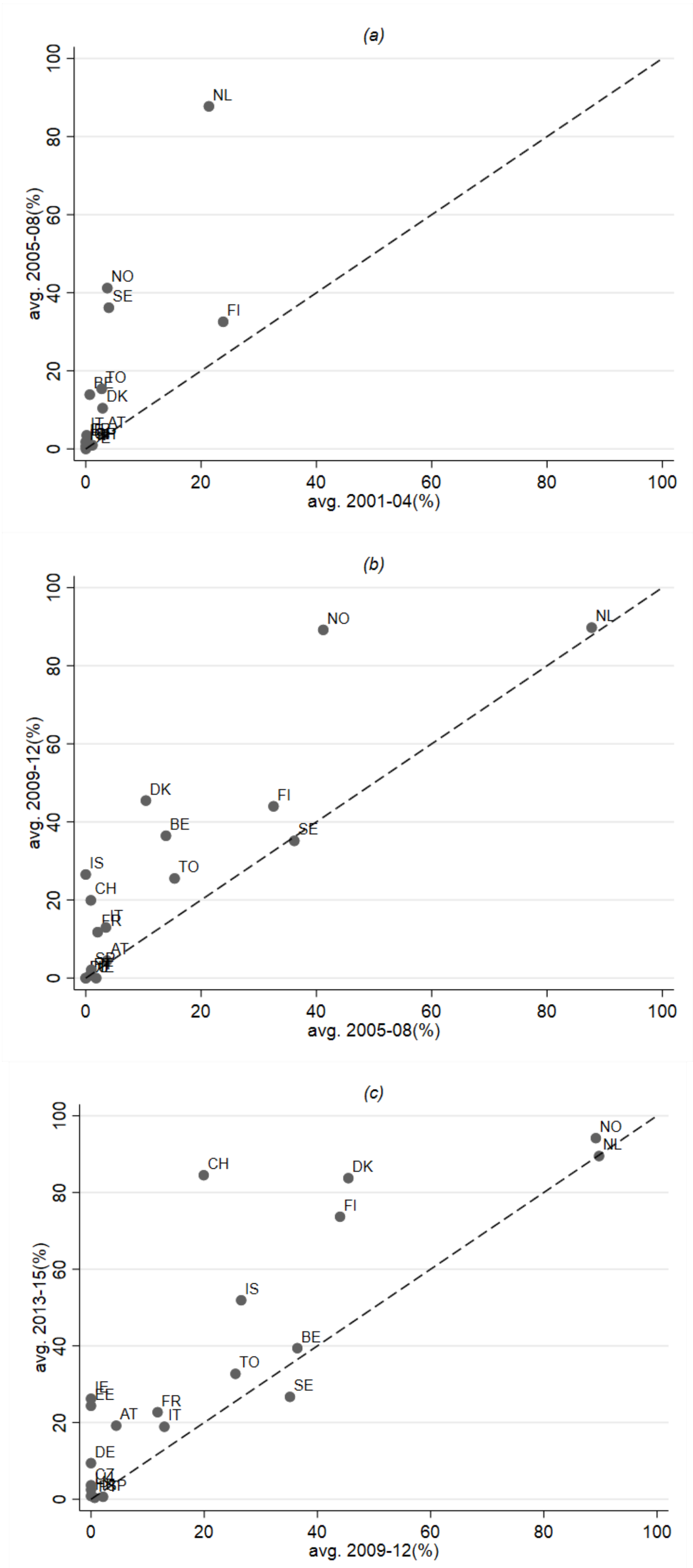

Figure 2: The certification rate per country, 2001-2015. Note: Each plot compares the 4-year average with the preceding 4-year average from 2001-2015 (one 3-year period: 2012-2015). Source: own calculations, AIB, Eurostat, IEA.

5.2 Churn rate

Table 1 provides the summary statistics of the three different churn rates which approximate final demand for consumption differently[6]. While all churn rates suggest very low average churn rates, the level of the churn rate depends on the approximation. The mean of the churn rate based on cancellations (0.46) is more than double the mean of the churn rate based on issuance (0.21). The churn rates based on last year's issuance and cancellations are more similar, both in terms of the means and standard deviations. This also holds for most individual years (not reported here). This suggests that current cancellations tend to follow previous year's issuance closer than current year's issuance.

The churn rate in all individual countries remains low. Figure 3 compares the simple average of the three churn rates per country between four time periods: 2001-2004 with 2005-2008 (panel a), 2005-2008 with 2009-2012 (panel b) and 2009-2012 with 2013-2016 (panel c). In all periods, the average churn rate remains below 3. To facilitate readability, observations in the origin are omitted (but mentioned in the figure). These observations reflect countries with active certification but zero domestic transfers, resulting in a churn rate of zero. In 2009-2012, Austria is the first and only country where the churn rate exceeds 1 (1.4). The highest churn rates are observed in Estonia (2.2) and Italy (2.5), both in the most recent period. The certificate market in other countries do not experience churn rates above 1.5 in any of the periods. These churn rates are well below 10, a commonly applied benchmark for a liquid market.

The churn rate does appear to be increasing in most countries. In panel a, 8 out of 12 countries are located above the diagonal, indicating the churn rate increased from 2001-2004 to 2005-2008. This concerned Belgium, Germany, Denmark, Finland, France, Netherlands, Norway and Sweden. Decreases occur in Austria, Switzerland and Italy. No trade at all occurred in both periods in Spain. In the next period (2009-2012), relatively more decreases (5) occur, as compared to the second period. Switzerland, Finland, France, Italy, and Sweden experience decreases while Austria, Belgium, Germany, Denmark, Luxemburg, Netherlands and Norway experience increases. No trade in the two considered periods was reported in Ireland, Portugal and Spain. In the final period (2013-2016), the churn rate rises in 14 out of 19 countries: Belgium, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Iceland, Italy, Ireland, Luxembourg, Norway, Spain and Sweden. The churn rate decreased in Austria, Finland and Netherlands. No trade in both of these periods was reported for Portugal and Switzerland.

For all countries combined, all three churn rates display an increasing trend over time (figure 4). The churn rates increased on average 14.5% (whole area) and 16.7% (weighted average) per year from 2002-2016. However, the scores of 1.65 (whole area) and 0.56 (weighted average) in 2016 are very poor. In each year since the start of the market, the churn rates scored lower than 2, far below levels generally considered as liquid.

Table 1: Summary statistics of three churn rates on the level of individual countries.

	x^1	**x^2**	**x^3**
Mean	0.21	0.36	0.46
Standard deviation	0.50	0.85	0.85
Minimum	0.00	0.00	0.00
Maximum	5.69	7.22	6.71

Note: The first churn rate (x^1) approximates final demand for consumption by the number of issued certificates, the second (x^2) by the number of issued certificates in the previous year and the third (x^3) by the number of cancelled certificates. Source: own calculations, AIB.

[6] After calculating the churn rates, 6 curious observations in 5 countries were deleted (Czech Republic, Finland, Germany, Italy, and Iceland). See Appendix B for clarification.

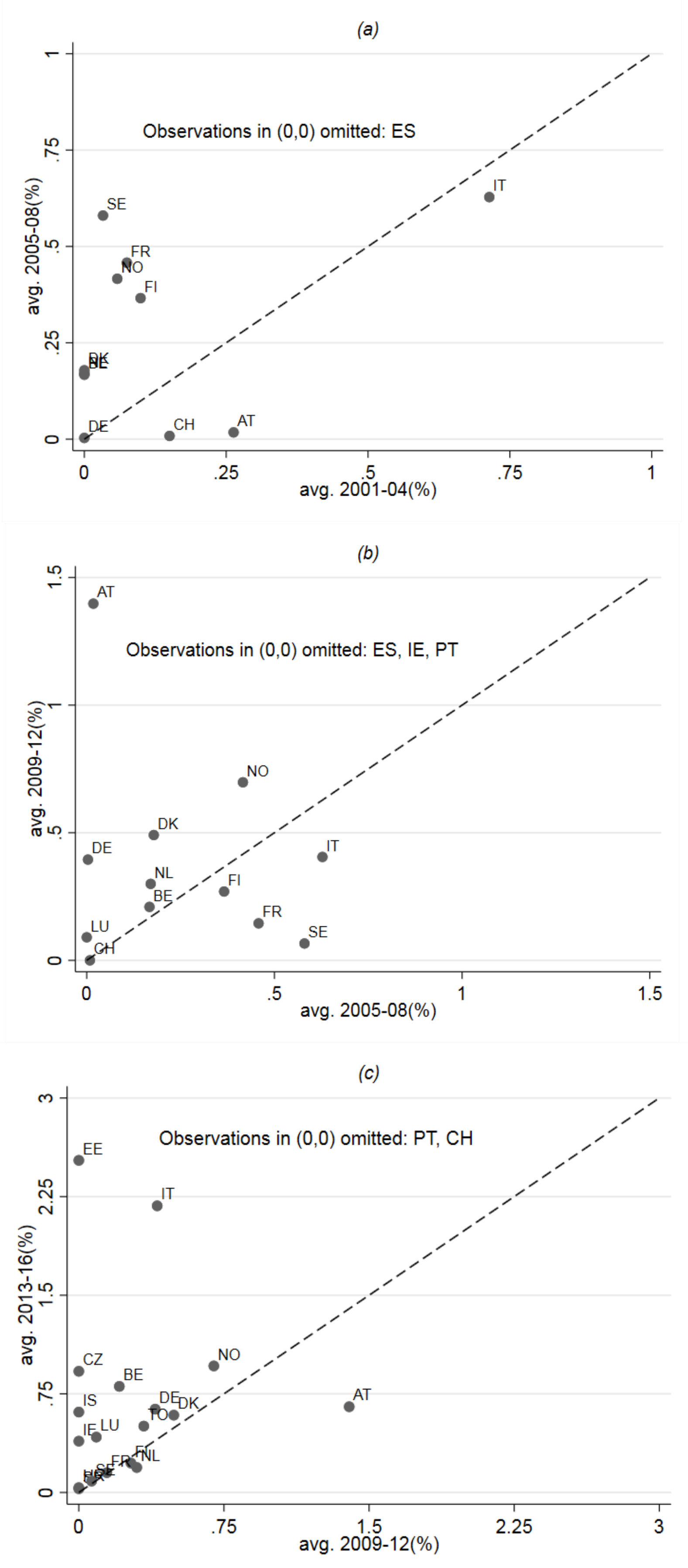

Figure 3: Churn rate per country, 2001-2016. Note: Each plot compares the 4-year average with the preceding 4-year average from 2001-2016. Differences in scaling are chosen to enable identification of individual countries in graphs. Source: own calculations, AIB.

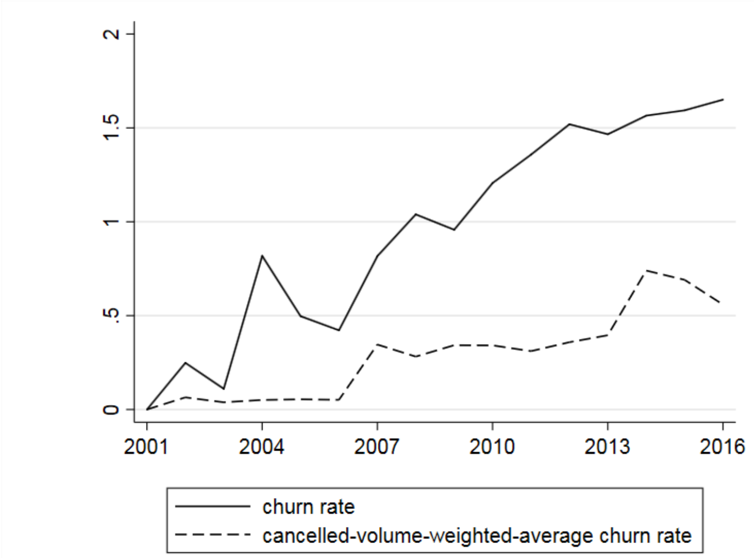

Figure 4: Churn rate in all countries combined, 2 types, 2001-2016. Source: own calculations, AIB.

5.3 Price volatility

Figure 5 shows the development of the prices for products for which we have most observations: Nordic, Italian and EU hydro (panel a) and EU biomass, solar and wind (panel b). At first glance, there appears some co-movement but, at times, peaks in some prices are hardly reflected in the other prices. Table 2 lists the correlation coefficients of the prices for which we have observations in multiple years. Some products are strongly correlated with each other such as the prices of EU hydro and EU wind certificates (0.92) while other products are uncorrelated or even negatively correlated, such as the prices of Italian hydro and EU solar. This indicates that certificates from different countries and technologies have their own price dynamics to some extent.

The volatility in certificate prices is relatively high. Table 3 reports the volatility in monthly spot prices. There are considerable differences in the volatility of different products but volatility tends to be quite high. In 2017, volatility ranged from 3.4% for Dutch wind certificates to 105.6% for Belgian wind certificates. The volatility in Nordic hydro certificates, one of the most liquid products, was 14.3%. Over time, the volatility generally has been fluctuating. The patterns do not suggest a considerable improvement over time.

Table 2: Correlation coefficients between certificate price series.

	Nordic Hydro	EU Biomass	EU Hydro	EU Solar	EU Wind	IT Hydro
Nordic Hydro						
EU Biomass	0.84					
EU Hydro	0.12	-0.03				
EU Solar	0.86	0.92	0.04			
EU Wind	0.57	0.58	-0.14	0.57		
IT Hydro	0.63	0.84	0.01	0.78	0.44	

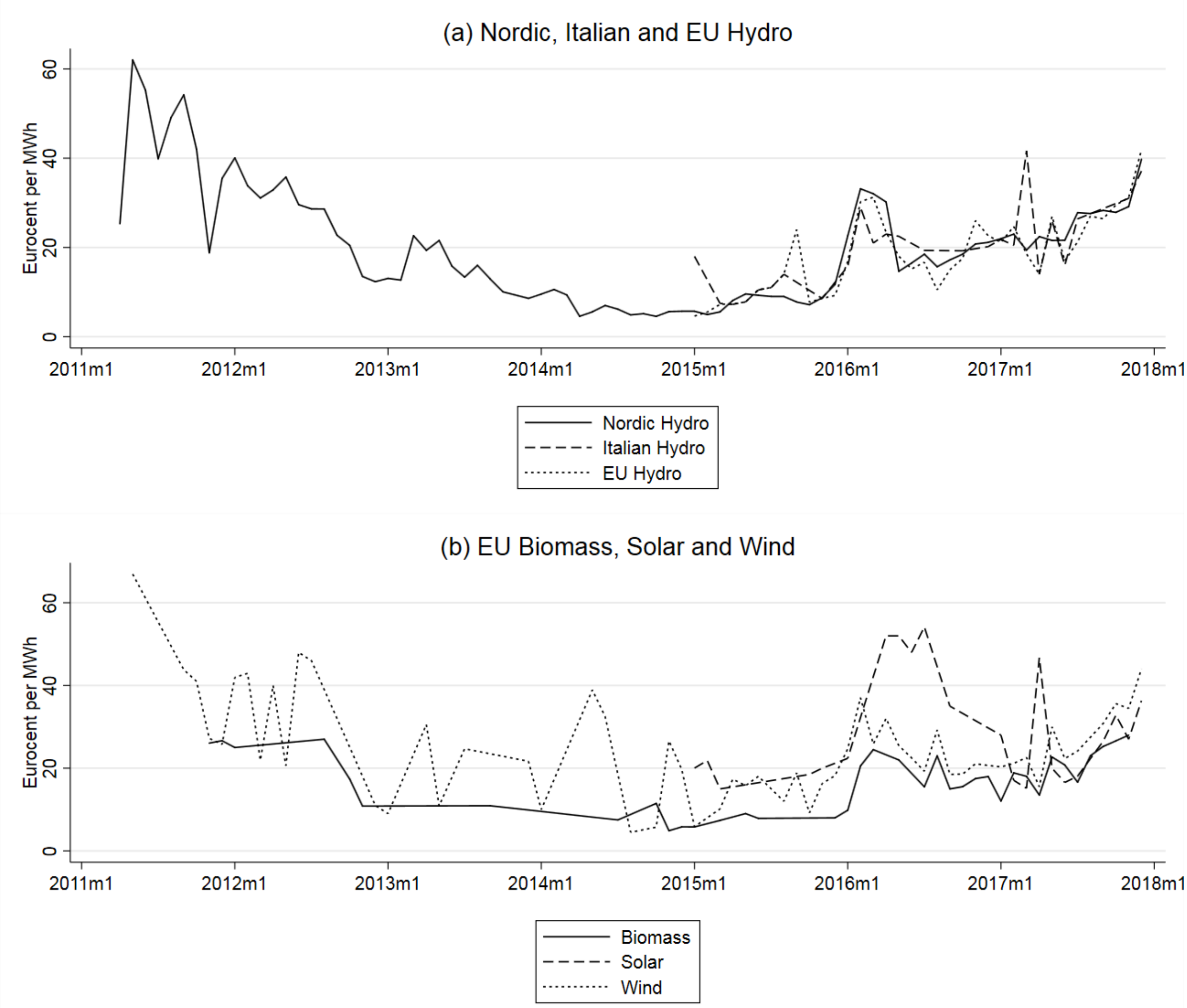

Figure 5: Spot prices for hydro GO certificates from different countries (panel a) and different EU products (i.e. country unspecified; panel b). Source: Greenfact.

Table 3: Volatility in monthly spot prices (annual averages).

Country	**Techno-logy**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Nordic	Hydro	66.6%	13.4%	31.2%	22.2%	19.0%	34.5%	14.3%
Belgium	Biomass							63.9%
	Solar							84.8%
	Wind							105.6%
EU	Biomass		22.2%		54.4%	8.9%	41.7%	33.3%
	Hydro					33.6%	40.7%	34.4%
	Solar					23.1%	10.4%	78.1%
	Wind	16.0%	69.0%	32.6%	198.0%	54.7%	30.0 %	34.3%
Italian	Hydro					15.7%	47.9%	59.8%
Nether-lands	Biomass							30.9%
	Wind							3.4%
Switzerland	Hydro							28.1%

Note: Volatility is measured as the standard deviation of monthly relative price changes.

5.4 Expiration rate

Figure 6 depicts the expiration rate per year from 2001-2016 in the whole region. The amount of expired certificates ranged between 5% and 25% from 2001-2003. From 2005-2016, the expiration rate appears more stable, being on average 6.5% and ranging from 2.4%-10.4%. This indicates that, while most certificates are cancelled, a substantial amount of certificates expires and therefore remains unused for proving the consumption of renewable electricity by end-users.

Figure 7 compares the expiration rate in individual countries between four periods: 2001-2004 with 2005-2008 (panel a), 2005-2008 with 2009-2012 (panel b) and 2009-2012 with 2013-2016 (panel c). We exclude the expiration rate in Luxembourg in 2011, 2012 and 2014 because they exceed 100%, which should be impossible. This is probably caused by inaccuracies in the database. Interestingly, the number of countries without expirations decreases from 9 in the first period (Austria, Belgium, France, Germany, Italy, Netherlands, Spain and Switzerland) to 2 in the last period (Austria and Portugal). Denmark and Norway have very high expiration rates (>38%) in the initial years, but these decrease to less than 5% in the most recent period. From 2009-2012, the expiration rate decreases to levels below 8% in all countries except for Denmark. However, in the most recent periods, expirations increase again in the majority of countries. Countries with expiration rates above 10% in the most recent period are Belgium, Czech Republic, Switzerland and Italy. Note that this includes countries with well-established certification systems such as Switzerland and Italy. Even in Germany and The Netherlands, countries that are very large importers, between 5%-10% of the certificates expire.

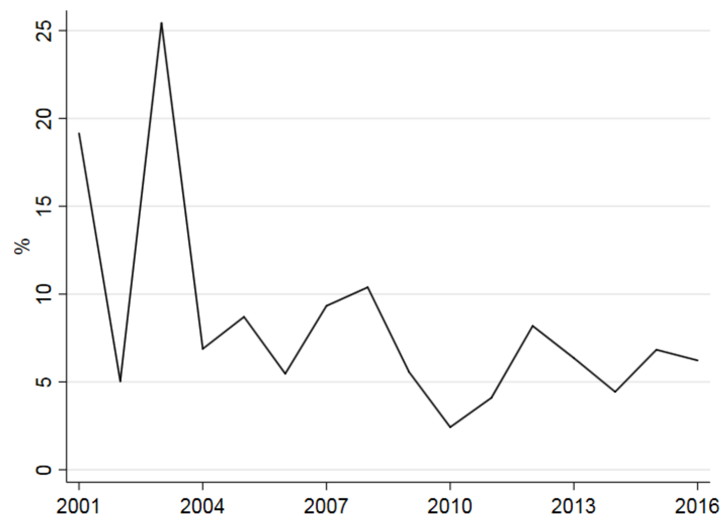

Figure 6: Expiration rate, all countries combined, 2001-2016. Source: own calculations, AIB.

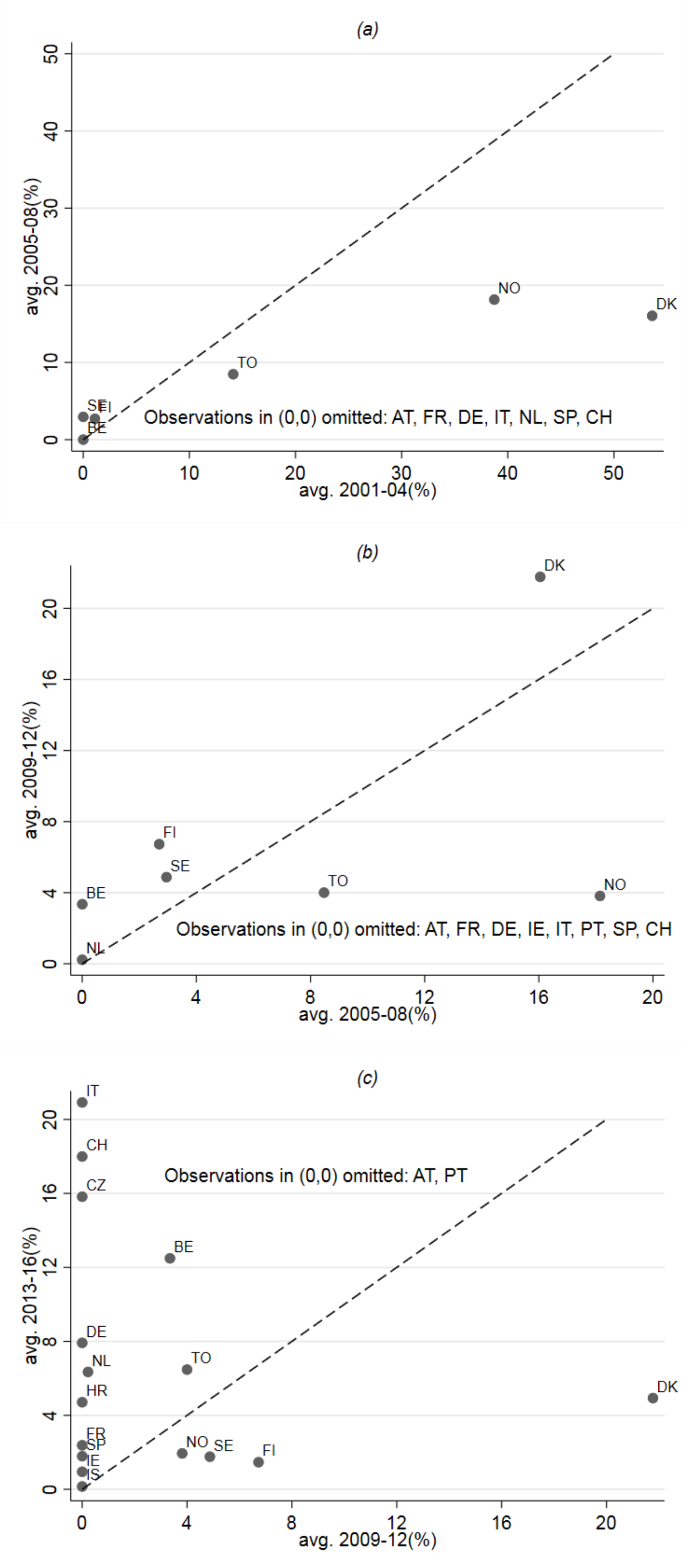

Figure 7: Expiration rate per country, 2001-2016. Note: Each plot compares the 4-year average with the preceding 4-year average from 2001-2016. Countries in (0,0) have active certification schemes. Differences in scaling are chosen to enable identification of individual countries in graphs. Source: own calculations, AIB.

6. Certificate design features and market performance

We analyse an unbalanced panel of 20 countries from 2001-2015 to assess the relationship between design and performance. The imbalance is caused by the fact that some countries start operating a certification scheme after 2001. There are also several years missing for the electricity prices of Croatia, Estonia and Iceland.

We apply a within estimation procedure to estimate the coefficients because the time-invariant individual effects may be correlated with some of our regressors, as discussed earlier. As a consequence, we do not obtain estimates for the time-invariant certification and export restriction control variables.

Statistical tests suggest the white-noise errors assumption is not satisfied. Autocorrelation tests, as proposed by Wooldridge (2002), do not suggest that autocorrelation is present in our specifications. However, likelihood-ratio tests suggest that the errors are heteroskedastic. Therefore, we compute White standard errors. We opt for this solution rather than the common practice of computing cluster-robust standard errors because our sample consists of 20 clusters, much lower than the commonly regarded threshold of 50 for reliable inference on the basis of cluster-robust standard errors (Cameron et al. 2008).

Table 4 reports our estimation results. Our estimation results imply that the presence of the international standard positively influences the amount of issued certificates. The estimated coefficient of 14.07 are significant at a 0.01 confidence level. This effect substantial: on average, the presence of the international standard positively affects the volume of issued certificates by about 14.1TWh, almost equal to the 2016 median volume of issued certificates (14.3TWh).

The estimated effect of the private nature of a certifier is negative and marginally significant (p-value 0.066). The coefficient of -5.88 is again substantial in size. A negative estimate suggests that private certifiers are associated with less output of certificates. If certification is honest, this is likely caused

Table 4: Fixed effects model estimation results, 2001-2015. Dependent variable: Volume of issued certificates (TWh).

	Coefficient	**Standard error**
International standard	14.07***	2.955
Private certifier	-5.875*	3.181
Renewable electricity generation (TWh)	0.167**	0.0801
GDP index	0.249*	0.148
Electricity price (€/kWh)	-38.48	37.94
Certification restriction policy	*Omitted*	
Export restriction policy	*Omitted*	
Constant	-33.86***	12.55
Observations	284	
R-squared	0.223	
Number of countries	20	

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

by higher certification fees charged by private certifiers, putting upward pressure on the supply curve. Supportive to this, three out of the four highest variable certification fees in 2015 were charged by private certifiers (AIB 2015). The highest fixed fee was also charged by a private certifier, more than 2.5 times higher than the second highest fee. Considering that these private certifiers tend to be highly regulated companies, frequently appointed following tender processes, it does not seem farfetched that these profit maximizing firms are oriented towards social welfare and provide honest certification, much in line with Mahenc's (2017) profit maximizing but sufficiently socially concerned certifier.

As expected, the generation of renewable electricity has a positive and significant effect on the output of certificates. The estimated coefficient for the GDP index is positive and marginally significant. There appears to be no significant effect of the electricity price on the amount of certification. The estimated coefficient is negative but insignificant.

7. Results and conclusion

Certification schemes are currently mainly present in electricity markets, but it is anticipated that such schemes will be introduced in other energy markets as well, such as markets for gas and hydrogen. As information asymmetry is an inherent market failure in these markets, it is important to verify whether certification schemes prove an effective mechanism to facilitate trade in renewable energy. The purpose of this paper is to investigate the development of the markets for electricity GO certificates in 20 European countries since the creation of these markets in 2001. We evaluate market performance by analysing (1) the share of certified renewable electricity, (2) the churn rate, (3) price volatility and (4) the share of expired certificates (a measure for excess supply). In addition, we relate market performance to two critical design features of certificate systems: the public/private nature of certifiers and the presence of a common international standard.

Overall, our results suggest that the markets for GOs remain still in their infancies. The share of renewable electricity that receives certification has increased in the EU as a whole and in most individual countries since 2001. In some well-established systems, such as Norway and Netherlands, almost all renewable electricity production receives certification. The share remains quite low in countries with younger certification systems but also in the well-established systems of countries like Italy (<20%).

The other performance indicators display a more pessimistic view. Market liquidity as measured by the churn rate is very poor in the whole region and all individual countries. The churn rates are far below levels which are generally associated with a mature and liquid market. Moreover, GO certificate prices are very volatile and there are no clear signs of improvement over time. For example, the annual price volatility in 2017 of Nordic hydro and EU wind certificates, two of the most liquid products, was 14.3% and 34.3%. In addition to poor liquidity and high volatility of prices, the market appears to be in a constant state of oversupply as a considerable amount of the issued certificates in Europe is never used to claim the consumption of renewable electricity. Several well-established systems such as the Austrian and Norwegian scheme experience very low expiration rates, but others experience significant high expiration rates such as the Italian (21%) and Swiss (17%) schemes.

Our analysis indicates that certification-scheme design choices affect market outcomes. We find that private certifiers are associated with lower market volumes. These lower volumes are likely to be explained by higher certification fees charged by private certifiers. This is in line with the predicted behaviour of Mahenc's (2017) profit-maximizing certifier that is sufficiently socially concerned. In contrast, adopting a common international standard appears to have a strong positive affect on market volumes.

Two data-related caveats of our analysis should be mentioned. First of all, our certification database is incomplete as observations for 2 countries were partly missing. Second, a few errors were discovered in the certification data. Although serious, we believe that we were able to handle these errors and obtained meaningful results.

This paper provides a detailed overview of the performance of the most developed certificate system in Europe. This is informative about the success of certificates as a mechanism to trade renewable energies and improves our understanding of the effective design of certificate systems of other energy carriers. Particularly, lessons can be drawn for the further development of a European certification system for renewable gas.

Renewable gas volumes are currently very low but are expected to increase in the future according to some studies (Ahern 2015, EURACTIV 2017). Currently, the landscape of renewable gas certification schemes in Europe is scattered with no common European framework and very significant differences in designs between countries (Spijker et al. 2015). Our analysis implies that policies that promote a common standard and public ownership over the certifier have a positive effect on volumes in certificate markets for renewable hydrogen or gas. Nevertheless, this may not suffice to create well-functioning certificate markets since, after almost two decades of trading, concerns remain regarding the performance of certificates markets in terms of liquidity and volatility. Policies aimed at improving market transparency can also benefit market efficiency. Currently, a lack of transparency surrounds certificate markets, particularly with respect to prices. This harms the confidence of market participants with respect to certificate price formation, potentially deterring market participants.

A potential contributor to the rising volumes of renewable gas is the power-to-gas technology. This developing technology enables producing renewable methane (but also other gaseous fuel types) out of water, renewable electricity and CO_2. This deliverable was written as part of the STORE&GO research project that, in addition to demonstrating the feasibility of the power-to-gas technology, investigates the potential economic barriers for the diffusion of power-to-gas. A lacking or improperly-designed certification scheme forms a potential economic barrier and may hamper the diffusion of power-to-gas. This is particularly the case when the technology faces strong competition from fossil production technologies (for which the market price does not depend on a certification scheme) and other forms of (renewable) energy, because a properly designed certificate enables power-to-gas producers to reap the willingness-to-pay of consumers, i.e. higher prices. In the absence of a properly designed certification scheme, the resulting market failure of adverse selection will hurt power-to-gas producers. In this analysis, we show that two critical design features that contribute to a well-designed scheme for renewable methane are international standardisation of certification schemes and public ownership over the certifier.

References

ACER (2016). REMIT annual report 2016.

ACER/CEER (2017). Annual report on the results of monitoring the internal electricity and gas markets in 2016. Electricity wholesale markets volume.

ACM (2014). 2014 liquidity report. Wholesale markets for natural gas and electricity.

Ahern, E., Deane, P., Persson, T., Gallochoir, B. and Murphy, J. (2015). A perspective on the potential role of renewable gas in a smart energy island system. *Renewable Energy, 78*, 648-656.

AIB (2015). *AIB 2015 member tariffs*.

AIB (2017). A*nnual statistics Q2 2017*. Available at https://www.aib-net.org/aib_activity_statistics.

Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics, 84*(3), 488-500.

BIOSURF (2016). Guidelines for creating the European biomethane guarantees of origin. *Deliverable 3.3 of the BIOSURF research project.*

Bollino, C. (2009). The willingness to pay for renewable energy sources: The case of Italy with socio-demographic determinants. *The Energy Journal, 30*(2), 81-96.

Cameron, A., Gelbach, J. & Miller, D. (2008). Bootstrap-based improvements for inference with clustered errors. *Review of Economics and Statistics, 90*(3), 414-427.

Cason, T. & Gangadharan, L. (2002). Environmental labelling and incomplete consumer information in laboratory markets. *Journal of environmental economics and management, 43,* 113-134.

Certiq (2018). *Annual reports 2002-2016*. Retrieved from http://www.certiq.nl/wij-zijn/publicaties/jaarverslagen/

Dosi, C. & Moretto, M. (2001). Is ecolabelling a reliable environmental policy measure? *Environmental and Resource Economics, 18*, 113-127.

EBA (2016). *BIOSURF project serving the evolution of the European biomethane market.*

Elofsson, K., Bengtsson, N., Matsdotter, E. & Arntyr, J. (2016). The impact of climate information on milk demand: evidence from a field experiment. *Food Policy, 58,* 14-23.

EURACTIV (2017). Renewable Gas. Special Report.

Feddersen, T. & Gilligan, T. (2001). Saints and Markets: Activists and the supply of credence goods. *Journal of Economics & Management Strategy,* 23, 149-171.

Fuerst. F. & McAllister, P. (2011). Eco-labelling, rents sales prices and occupancy rates: do LEED and Energy Star labelled offices obtain multiple premiums? *Ecological Economics, 70*(6), 1220-1230.

Heather, P. 2015. The evolution of European traded gas hubs. *OIES paper: NG104.*

Hornibrook, S., May, C. & Fearne, A. (2015). Sustainable development and the consumer: exploring the role of carbon labelling in retail supply chains. *Business strategy and the environment, 25*(4), 266-276.

Kamerschen, D. and Porter, D. (2004). The demand for residential, industrial and total electricity, 1973-1998. *Energy Ecoomics 26*(1), 87-100.

Lizzeri, A. (1999). Information revelation and certification intermediaries. *The RAND journal of Economics, 30*(2), 214-231.

Mahenc, P. (2017). Honest versus misleading certification. *Journal of Economics & Management Strategy, 26*(2), 454-483.

Mattoo, A. & Singh, H. (1994). Eco-labelling: policy considerations. *KYKLOS 47*, 53-65.

Mol, A. & Oosterveer, P. (2015). Certification of markets, markets of certificates: Tracing sustainability in global agro-food value chains. *Sustainability, 7*, 12258-12278.

Mozumder, P., Vásquez, W. & Marathe, A. (2011). Consumers' preference for renewable energy in the southwest USA. *Energy Economics, 33*(6), 1119-1126.

Nordhaus, W. D. (2006). Geography and macroeconomics: New data and new findings. *Proceedings of the Natural Academy of Sciences of the United States of America, 103*(10), 3510-3517.

Ofgem (2009). Liquidity in the GB wholesale energy markets. Ref 62/09.

Park, J. (2017). Is there a price premium for energy efficiency labels? Evidence from the introduction of a label in Korea. *Energy Economics, 62*, 240-247.

Regnier, E. (2007). Oil and energy price volatility. *Energy Economics, 29*(3), 405-427.

Roe, B. R., Tesil, M. F., Levy, A. & Russell, M. (2001). US consumers' willingness to pay for green electricity. *Energy Policy, 29*, 917-925.

Spijker, E., Jepma, C., Hofman, E., Joosten, G., Hoenders, L., Eisenack, K., Neubauer, L., Hoensch, S., Brunekreeft, G. & Palovic, M. (2015). A level playing field for the European biogas and biomethane markets. Case of the Netherlands and Germany: policy environment, key differences and harmonization issues.

Sundt, S. & Rehdanz, K. (2015). Consumers' willingness to pay for green electricity: A meta-analysis of the literature. *Energy Economics, 51*, 1-8.

UN (2015). Paris Agreement.

Wooldridge, J. (2002). Econometric analysis of cross section and panel data. *Cambridge, MA*: *The MIT Press.*

Appendix A. Descriptive statistics.

Table A.1: Descriptive statistics for all variables except for GO certificate prices (all yearly averages).

Certification		2001–2004	2005–2008	2009–2012	2013–2016
Issued volume (TWh)					
	min	0.00	0.00	0.00	0.00
	max	8.26	111.08	135.70	136.11
	mean	0.81	5.57	10.83	18.82
	SD	1.88	16.58	25.94	30.43
Cancelled volume (TWh)					
	min	0.00	0.00	0.00	0.00
	max	7.55	28.75	43.81	87.59
	mean	0.38	3.06	9.86	15.85
	SD	1.23	6.34	13.22	19.70
Domestically transferred volume (TWh)					
	min	0.00	0.00	0.00	0.00
	max	0.54	39.58	43.76	88.99
	mean	0.03	1.00	4.67	11.98
	SD	0.10	4.71	9.18	20.57
Expired volume (TWh)					
	min	0.00	0.00	0.00	0.00
	max	0.54	39.58	43.76	88.99
	mean	0.03	1.00	4.67	11.98
	SD	0.10	4.71	9.18	20.57
Imported volume (TWh)					
	min	0.00	0.00	0.00	0.00
	max	8.35	28.14	52.89	80.31
	mean	0.21	2.15	8.22	14.31
	SD	1.23	4.97	13.12	20.50
Exported volume (TWh)					
	min	0.00	0.00	0.00	0.00
	max	6.43	50.54	134.49	161.82
	mean	0.20	2.03	8.10	14.19
	SD	0.94	7.08	21.83	29.29
Renewable electricity production (TWh)					
	min	0.01	0.01	0.04	0.32
	max	131.39	142.97	159.98	203.70
	mean	31.05	35.21	42.21	50.75
	SD	34.20	38.61	44.16	54.07
Electricity price (€/kWh)					
	min	0.05	0.07	0.09	0.11
	max	0.23	0.27	0.30	0.31
	mean	0.13	0.15	0.18	0.19
	SD	0.04	0.05	0.05	0.05
GDP index					
	min	75.30	88.30	94.20	90.20

max	100.60	121.20	112.20	149.70
mean	88.02	99.90	100.36	105.71
SD	5.84	5.68	2.72	9.60

Sources: *Certification:* AIB; *Renewable electricity production, electricity price (both except for Switzerland) and GDP index*: Eurostat; *Swiss renewable electricity production:* IEA; *Swiss electricity price:* Swiss Federal Office of Energy.

Table A.2: *Descriptive statistics of GO certificate spot prices (all yearly averages; €/MWh).*

Location	**Technology**		**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Belgium	Biomass								
		min						38.00	19.20
		max						38.00	54.37
		mean						38.00	36.40
		SD							8.71
	Solar								
		min							35.00
		max							84.71
		mean							58.28
		SD							23.31
	Wind								
		min							27.00
		max							103.24
		mean							56.19
		SD							28.67
EU (un-specified)	Biomass								
		min	26.07	10.85	10.93	4.88	5.81	9.85	12.07
		max	26.66	27.01	10.93	11.50	9.05	24.50	28.00
		mean	26.36	20.06	10.93	7.43	7.62	18.15	20.50
		SD	0.42	7.41		2.92	1.18	4.44	5.21
	Hydro								
		min					4.62	10.50	14.00
		max					24.00	31.25	41.84
		mean					9.80	20.28	24.97
		SD					5.13	6.43	7.43
	Solar								
		min					15.00	22.38	15.15
		max					21.86	54.15	46.71
		mean					19.08	43.92	25.84
		SD					2.57	12.61	9.86
	Wind								
		min	25.75	11.00	9.00	4.50	5.86	18.50	15.51
		max	66.93	48.00	30.55	38.93	18.87	37.05	44.00
		mean	40.94	34.05	19.36	19.71	14.17	24.58	27.36
		SD	16.61	14.01	9.19	13.54	4.53	5.79	8.37
Italy	Hydro								
		min					7.25	15.77	14.00
		max					18.00	29.00	41.67

		mean					10.57	21.26	26.06
		SD					3.77	3.85	9.26
Nether-lands	Biomass								
		min						45.00	23.00
		max						45.00	66.50
		mean						45.00	36.26
		SD							13.18
	Solar								
		min							225.00
		max							365.00
		mean							280.00
		SD							74.67
	Wind								
		min							233.40
		max							451.50
		mean							315.73
		SD							73.22
Nordic	Hydro								
		min	18.83	12.33	8.60	4.56	4.97	14.66	19.40
		max	62.02	40.08	22.65	10.59	11.73	33.15	39.77
		mean	42.45	27.47	15.10	6.57	8.06	21.75	25.88
		SD	14.30	8.60	4.51	2.10	1.95	6.50	5.51
Switzerland	Hydro								
		min							70.38
		max							496.99
		mean							282.22
		SD							171.74

Source: Greenfact

Appendix B. Construction of churn rates and data issues.

In Czech Republic, Finland and Italy the churn rates based on cancellations spike to unrealistically high levels in the very first year of operation (e.g. 30 in Finland). These rates all drop after the first year and both the churn rates based on issuance do not spike. The majority of these certificates was most probably cancelled (or expired) in the next year, inflating the churn rate based on cancellations in the first year of operation. For these three countries, we can be quite certain that the spikes are caused by the way we constructed the churn rates. For Germany, both the churn rate based on issuance and last year's issuance spike in 2002 to more than 1000 and 3000 respectively. These spikes are caused by an extremely high level of domestic transfers (more than 513,000) in 2002. In 2001 and 2002 combined, there were less than 600 certificates issued and no imports at all. Moreover, no transfers at all were conducted in Germany in any other year between 2001 until 2007. Also, no cancellations occurred until 2004. This gives sufficient reason to believe that the number of 513,000 transfers does not represent the actual traded volume in Germany in 2002. In Iceland, the churn rate based on cancellations spikes to 243 in 2015 (coming from 0.37 in the previous year). This is caused by a concurrent decrease in cancelled volume of 89% and massive increase in transferred volume of 7410%. We cannot conclude that our calculation of the churn rates causes the spike nor that it is caused by suspicious reporting. Two signals that the spike does not represent the actual state of liquidity in 2015 are (i) the other two churn rates in that year which take on plausible values and (ii) the same churn rate (based on cancellations) in 2016, which drops again to 1.8. Moreover, even in the most mature and liquid markets, churn rates of 243 are rarely observed. Therefore, we omit this observation.

Acknowledgements

This project received financial support from the Horizon 2020 research and innovation programme (grant No. 691717). We are thankful for the support of Phil Moody from the Association of Issuing Bodies. We also thank Helge Föcker from Uniper for helpful comments.