HyDelta

WP8 – Admixing

D8.4 – Economic aspects of Mandatory Hydrogen Blending Quota Schemes

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Executive summary

Both the EU and some governments of EU Member States recently formulated proposals to green the gas system with the help of mandatory blending schemes, i.e. mixing natural gas with greener gases such as biobased gases and/or clean hydrogen (independently if the different types of gases are mixed within the same pipes, and/or mixed by allocating specific parts of the gas grid for specific types of gases). The underlying idea is to stepwise turn the natural gas system into a green gas system. In most of the proposals certificate trading is part of the suggested blending strategy recognising that any certificate-based blending can only be realized on the basis of physical introduction of the renewable gases.

Currently blending is applied in various markets but in gas markets it only exists by admixing biobased gas on a voluntary basis. That is why the concept to blend clean hydrogen into the natural gas mix on a mandatory basis is lacking any real life experiences, and therefore will have to be developed. This paper assesses how such a regime could be introduced such that it really works well from an economic and societal perspective by screening the existing literature on critical points regarding similar blending practices in other energy markets. In doing so a particular issue turned out to be how to deal with the policy dilemma's that characterised all options to try to deal with quota scheme 'weak spots'.

We found three issues to be the dominant concerns that need to be carefully considered in the design of any mandatory blending scheme.

A first key issue relates to the certificate market that is a crucial component of almost all suggested blending schemes. It seems crucial to make sure that the certificates are accepted to be completely reliable and environmentally sound right from the beginning, i.e. the blending scheme introductory phases. Also the certificate trading process needs to be transparent as possible from the beginning which means that transparency is key even in the introductory trading stage that likely is dominated by bilateral or 'over the counter' trading, long-term contracts, and a limited number of market parties. An example how the market transparency can be increased without providing sensible information of individual trades, is periodically publishing total traded volumes and average certificate prices, for example by brokers or exchange platforms.

The main dilemma's one is facing is to get trading and market development off the ground if trading margins are very thin while trading volumes are still small. In such conditions public support may needed to set up professional trading platforms and bear related costs before the market spontaneously develops towards maturity, because private traders enter the scene. Another dilemma relates to traded products. Investors may prefer long-term contracts to mitigate their risks, which may be required in the beginning but a market consisting of long-term bilateral contracts is one where existing, powerful players will dominate and no new entrants see a chance to enter. In other words, it is in conflict with the wish to create market liquidity and transparency so that also in this regard one has to find the proper balance as the market matures. A final dilemma may be to create a first class certificate reputation right from the start. This requires watertight processes of validation and verification based on authorised and advanced schemes that are accepted throughout the trading area. Having all this in place, however, may be time consuming and costly such that it unduly slows down the development of quota and start of quota pilots. The same applies for getting international consensus on quota design and certificate specifications: getting there may take very long but seems at the same time indispensable for opening up international certificate trading.

A second key issue relates to the risk of heavy certificate price volatility. This may be a serious risk not only in the early stages of certificate trading where volumes are still small and relatively large volume

shifts in supply and demand may occur easily causing strong certificate price movement, but also in the mature stages as experiences in various emission trading schemes have shown. The reason is that mandatory blending quota essentially are based on volume driven policies leaving price formation to the market in which elasticities both of demand and supply are often low and regulatory risk high. Certificate price volatility therefore may typically be a systematic characteristic of mandatory blending quota schemes, which may frustrate the ultimate scheme target namely to incentivise investors to turn towards greener technologies. Their risk aversion may cause them to take a wait-and-see attitude.

That is why measures may be needed to try to restrict certificate price volatility, especially at the start, either by introducing minimum and maximum certificate prices, or by trying to steer price formation, or a combination of multiple measures. All options to do so, however, also have their backdrops. Guaranteeing minimum prices does require a fund and therefore lender at last resort to be able to purchase certificates against prices above market price levels; maximum prices may cause the quota to be surpassed and set a limit on the revenues that producers can make; and steering certificate prices via a flexible allocation regime increases regulatory risks which may paralyse investors. Yet a carefully balanced cocktail against undue volatility seems necessary. The measures can be stronger in the beginning and decline as the maturity and stability of the market evolves over time.

A third key issue relates to the degree of quota differentiation. This again may give rise to dilemma’s. One perspective is to start from technology neutrality based on the notion that the market, not the policymaker should determine which production technologies are chosen to achieve the ultimate target, which is emission reduction. Another perspective, however, could be that one wants to prevent a lock in of an assumed ultimately most cost-effective technology by introducing a quota differentiation giving some priority to a currently less cost-effective but expected future more cost-effective technology. This perspective can even go a step further by, besides economic, distinguishing even more categories of technologies based on other reasons, or if it is perceived important that the future portfolio requires a mix of different technologies. There are multiple measures described to apply quota differentiation, including their advantages and disadvantages. The dilemma clearly is that the support for future cost-effectiveness of technologies is inherently uncertain and that at short notice less cost-effective technologies are prioritised via quota on the one hand, but that risks of lock-ins are prevented.

The paper has clarified all the above dilemma’s based on experiences from real-life quota schemes and indicated the pro’s and cons of the various choices. The advice of this report is to take into account the three issues described above very carefully, if mandatory blending of hydrogen is implemented. How the dilemma’s will be solved ultimately, by weighting the advantages and drawbacks, will require political decision making.

Samenvatting

Zowel de EU als overheden van haar lidstaten hebben recent voorstellen opgesteld om het gassysteem te vergroenen door middel van bijmengverplichtingen, i.e. het uitbreiden van de gasmix met groene gassen zoals biomethaan en/of schone waterstof (los van of deze mix plaats vindt in dezelfde buisleidingen, en/of door allocatie van specifieke delen van het gasnet voor specifieke typen gas). Het onderliggende idee is om het gassysteem stapsgewijs te vergroenen. In veel van de voorstellen is het verhandelen van certificaten onderdeel van de gesuggereerde bijmengstrategie, wat alleen plaats kan vinden zolang hernieuwbare gassen fysiek in het systeem worden ingebracht.

Hedendaags is bijmenging toegepast in verschillende markten, maar in de gasmarkten wordt dit vooralsnog alleen toegepast met biomethaan op vrijwillige basis. Hierdoor is er nog geen ervaring met het verplicht bijmengen van schone waterstof in de praktijk, wat dus vooralsnog in ontwikkeling is. Dit rapport analyseert hoe zo'n regeling geïntroduceerd zou kunnen op een manier die werkt vanuit een economisch en maatschappelijk perspectief. Deze analyse is gedaan op basis van reeds bestaande literatuur die zich heeft gebogen over bestaande bijmengverplichtingen in andere energiemarkten. In het bijzonder is hier gekeken hoe met regelgevende dilemma's om te gaan, en welke opties er zijn om de 'zwakkere punten' van quota regelingen te mitigeren.

We hebben hierbij drie dominante issues gevonden die zorgvuldig overwogen moeten worden bij het opzetten van verplichte bijmengregelingen.

Het eerste dominante issue heeft betrekking op de certificatenmarkt, welke een cruciale component is in bijna alle verplichte bijmengregelingen. Het is cruciaal dat het certificatensysteem vanaf begin af aan, dus al in de introductie fase, erkend wordt als betrouwbaar en milieuvriendelijk. Daarnaast zal de wijze waarop certificaten verhandeld worden zo transparant mogelijk moeten zijn, zelfs in de introductie fase waarin het aannemelijk is dat de meeste transacties bilateraal of 'over-the-counter', via lange termijncontracten zullen verlopen tussen een gelimiteerd aantal spelers.

Het hoofdzakelijke dilemma dat wordt gezien, is om de handel en markt te ontwikkelen terwijl de marges en volumes klein zijn. Onder deze omstandigheden zou publieke ondersteuning nodig kunnen zijn om professionele handelsplatformen, met hun benodigde kosten, op te zetten, in plaats van voor een spontaan beloop te kiezen dat overgelaten wordt aan private handelaren. Een ander dilemma relateert aan de verhandelde producten. Investeerders zullen de voorkeur geven aan lange termijncontracten die risico's verlagen, maar dit staat in contrast met de wens om een liquide, transparante markt te ontwikkelen. Er zal dus een balans moeten worden gevonden die zich ontwikkeld met het volwassen worden van de markt. Tenslotte is er het dilemma om, vanaf de start, een eerste klas certificatie reputatie te verwerven. Dit vereist waterdichte processen voor de validatie en verificatie door geautoriseerde en geavanceerde regelingen, die ook worden ondersteund vanuit de potentiële gebruikers. Het is voor te stellen dat het ontwikkelen hiervan tijd in beslag zal nemen, wat dus ook een belangrijk onderdeel is van de overwegingen. Hetzelfde geldt voor internationale bindende doelen en specificaties voor certificaten: het opstellen duurt lang maar het is onmisbaar voor internationale handel.

Een tweede dominant issue is het risico voor hoge prijs volatiliteit. Dit is niet alleen een risico in de jonge fase van certificaat systemen, wanneer de volumes klein zijn en er relatief grote schommelingen in vraag en aanbod kunnen voorkomen, maar ook in volwassen fases, zoals meerdere emissiehandel systemen hebben laten zien. De reden is dat bijmengverplichtingen volume-gedreven mechanismen zijn die prijsformatie open laten aan de markt, waarvan de prijselasticiteit van zowel vraag als aanbod relatief laag is en de regelgevende risico's hoog. Prijs volatiliteit van de certificaten is daarom een

systematische karakteristiek van bijmengverplichtingen, wat het ultieme doel van het systeem in de weg kan zitten: namelijk investeerders verleiden om voor groene technologieën te kiezen. Hun risico-aversie kan ertoe leiden dat zij afwachtend zullen zijn.

Dit is waarom maatregelen mogelijk nodig zullen zijn om de volatiliteit in de certificaat prijs vanaf het begin al te beperken, door bijvoorbeeld het introduceren van minimum en maximum certificaat prijzen, door het implementeren van mechanismen die de certificaatprijs kunnen sturen, of natuurlijk meerdere maatregelen tegelijkertijd. Alle opties hebben echter nadelen. Het garanderen van minimum prijzen kan niet zonder een fonds en geldschieter die als laatste redmiddel certificaten boven de marktprijs koopt; maximum prijzen kunnen ervoor zorgen dat het quotum niet gehaald wordt en limiteren de potentiële opbrengsten van producenten; en het sturen van certificaatprijzen via een flexibel mechanisme verhoogt de risico's die investeerders zullen waarnemen. Dus, een gebalanceerde cocktail om overmatige volatiliteit tegen te gaan lijkt een vereiste.

Een derde dominant issue heeft te maken met de mate van differentiatie binnen het quotum. Ook dit kan leiden tot dilemma's. Aan de ene kant wordt verondersteld dat een technologie neutrale markt, in plaats van beleidsmakers, het beste in staat is te kiezen welke technologieën benodigd zijn om het ultieme doel te bereiken, namelijk emissie reductie. Aan de andere kant, moet er worden gewaakt voor een 'lock in' van een potentiële toekomstige meest kosten-efficiënte technologie, die nog relatief duur is wanneer het quotum wordt geïntroduceerd. Deze zienswijze kan nog verder gaan als, naast economische, naar meerdere redenen wordt gekeken waarom onderscheid tussen bepaalde categorieën van technologieën gemaakt moet worden, of er überhaupt een diverse mix van verschillende technologieën in de eindsituatie nagestreefd wordt. Meerdere maatregelen om differentiatie binnen het quotum toe te passen zijn beschreven, elk met hun voor- en nadelen. Het dilemma is dat ondersteuning aan toekomstige kosten-efficiënte technologieën inherent onzeker is, en dat op de korte termijn minder kosteneffectieve technologieën gestimuleerd worden, maar risico's op 'lock ins' worden voorkomen.

Dit rapport heeft de bovenstaande dilemma's uiteengezet, gebaseerd op ervaringen en analyses van bestaande quota regelingen met daarbij de voor- en nadelen van verschillende te maken keuzes. Het advies van dit rapport is om deze drie dilemma's in overweging te nemen, wanneer verplichte bijmengsystemen geïmplementeerd worden. Hoe met deze dilemma's zal worden omgegaan, en in welke mate de voor- en nadelen meegewogen zullen worden, is uiteindelijk een politieke beslissing.

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Abbreviations

CAPEX	*Capital Expenses*
CC(U)S	*Carbon Capture (Utilization) and Storage*
CO_2	*Carbon dioxide*
EPO	*European Patent Office*
(EU)ETS	*(European) Emission Trading System*
EU	*European Union*
FIT	*Feed-In-Tariff*
GoO(s)	*Guarantee(s) of Origin*
HBE(s)	*Hernieuwbare Brandstof Eenheid,* Renewable Fuel Entity
IREA	*(Barcelona's) Research Institute of Applied Economics*
MSR	*Market Stability Reserve*
OPEX	*Operational Expenses*
PtG	*Power-to-Gas*
PWEA	*Polish Wind Energy Association*
RED (II)	*Renewable Energy Directive*
RES(-E)	*Renewable Energy Source (Electric)*
RES	*Renewable Electricity Standards*
RO	*Renewables Obligation(s)*
RPS	*Renewable Portfolio Standard*
SDE(++)	*Stimulering Duurzame Energieproductie (en Klimaattransitie),* Stimulation of Renewable Energy production (and Climate transition)
SMR	*Steam Methane Reforming*
TGC	*Tradable Guarantee-of-Origin Certificates*
UK	*United Kingdom*
USA	*United States of America*

1. Introduction

With the increasing urgency of decarbonizing the energy system, the stress that electrification can have on a system's level and appliances that require high density energy carriers or green molecules as feedstock, the role of renewable and low-carbon gases in this energy transition is becoming more apparent. Because of the limited availability of biomass and the ongoing sustainability debate over the sources needed to produce biogas, hydrogen may become a cost-effective and practical alternative energy carrier.

However, it is perceived that without legislative interference renewable hydrogen will not come of the ground fast enough to play its foreseen role in decarbonization. Therefore, national and international governmental authorities are looking for measures to decarbonize the gas and fuel sector. As an example, the European Union (EU) called for multiple amendments in its Fit for 55 proposals that directly will impact the deployment and use of renewable hydrogen, such as:

- The 50% Renewable Fuel of Non-Biological Origin (RNFBO) target for hydrogen used in industry [1];
- The 2.6% RNFBO sub-target for transport fuels [1];
- The minimum share of 0.7% synthetic aviation fuels as part of 5% sustainable aviation fuels [2];
- Allowing until 5% hydrogen blended at cross-border points in existing gas infrastructure;
- More generically, not specific for renewable gas, there is aimed for 49% renewables in buildings [1].

If those proposals will be accepted it will have large implications for member states such as the Netherlands. It will mean that national legislations and support mechanisms should be in place to stimulate the use of these volumes of RFNBOs, where renewable hydrogen seems an unavoidable option. One of the mechanisms that can be used are mandatory admixing policies, which is the focus of this deliverable.

This deliverable is a part of a broader set of deliverables about mandatory admixing within the HyDelta research program. In HyDelta D8.1 'Admixing Literature review' [3] a literature review on various hydrogen blending quota schemes was provided, as well as a clear description of the similarities and differences between physical and virtual schemes. In HyDelta D8.2 'Assessment Admixing Schemes' [4], two existing mandatory and two voluntary admixing schemes are assessed to derive lessons that should be taken into account when implementing schemes for hydrogen. D8.3 'Pilots for introducing hydrogen blending quota' [5] suggested three potential quota designs and pilots that could be executed to further develop and optimize the schemes design before moving over towards a broader implementation.

This deliverable will complement the previous deliverables by investigating the potential economic risks and uncertainties that should be considered during the starting phase of mandatory quota obligations. The considerations that should be taken into account when implementing mandatory admixing policies including renewable and low carbon hydrogen are identified and investigated, reflecting on previous experiences of similar mechanisms in the electricity sector. The paper does not intent to perform price forecasts or other quantitative financial implications of certificate trading and mandatory blending.

First, the differences between volume and price based schemes are identified. Thereafter, the main economic risks, uncertainties and undesired developments in the starting phase of a certificate market are recognized. Following, measures to mitigate these negative effects in certificate markets are introduced and discussed. Lastly, the main take-aways to consider when implementing a hydrogen mandatory admixing schemes are discussed and conclusions are drawn. The findings of this deliverable are intended to be used for generic policy recommendations at the end of this work package.

2. General remarks about mandatory quota mechanisms

Multiple combinations of renewable energy carriers and economic incentives may stimulate the deployment of renewables. Quite some literature and experiences on this issue emerged in the first decade of this millennium. During that period, the European Union (EU) set its first EU-wide binding target for renewable energy. Thus, Member States started looking for optimal ways e.g. to deploy renewable energy production, which led to a vast literature on price-based vs volume-based incentive schemes [6] [7] [8] [9] [10] [11]. In price-based schemes, '*the government sets the price and the corresponding volume evolves depending on the respective cost-potential curve*' [10], whereas in volume-based schemes, '*the volume the scheme supports is predetermined and the price develops according to the existing resource conditions and technology costs*' [10]. For an overview, see Table 1.

Table 1 – Types of regulatory instruments [8]

		Price-driven	Quantity-driven
Regulatory	Investment focused	• Investment subsidies • Tax credits • Low interest/Soft loans	• Tendering system for investment grant
	Generation based	• Fixed premium system	• Tendering system for long-term contracts • Tradable Green Certificate system
Voluntary	Investment focused	• Shareholder Programs • Contribution Programs	
	Generation based	• Green tariffs	

In the literature on mandatory energy quota confusion may arise because different names are used for such schemes even if they are essentially conceptually similar, such as:

- Renewable Portfolio Standards (RPS) or Renewable Electricity Standards (RES): such standards oblige energy suppliers to produce a specified fraction of their energy from renewable sources. The names are mainly used in the USA.
- Renewables Obligations (RO): these are similar to RPS; this name is mainly used for the UK schemes.
- Tradable Green Certificates (TGC): these are similar to RPS; this name is mainly used in European countries.

Although names may differ, all schemes, however, have in common that tradable certificates are used to prove that a certain share of total energy produced, supplied or consumed, is renewable. That share is mandatorily imposed by a quota regulation; the quota-unit or certificate price formation is typically left to the market.

The main advantage claimed with respect to quota-based schemes is their compatibility with market principles namely a (potentially) competitive certificate price determination based on market forces [10]. The main disadvantage, however, is the uncertainty and often high volatility of certificate prices resulting in higher risk premiums for users compared to those of price-based schemes where the additional revenues of the support scheme are known in advance [10] [8].

This paper will assess sound economic conditions for introducing a specific volume-based incentive type, namely mandatory quota obligation schemes for renewable energy, and for clean hydrogen in particular.

3. Potential adverse developments in (early) quota certificate markets

Lessons learned from real-life experiments are a powerful information tool for exchanging ideas for improving: work processes, operations, quality, safety, and cost effectiveness, among other things. Moreover they may help to improve management decision making and implementation performance across all phases of a project. However, since no mandatory hydrogen quota scheme or certificate market is already up-and-running at the date of writing (end of 2021), in the following we will just discuss various issues that are especially, but not ultimately, faced in the introductory phase of comparable quota schemes to see what could also apply to future hydrogen schemes.

3.1 Risk of oversupply

Oversupply refers to a situation in which more supply enters the market than demand set by the quota target level. If it applies, certificate prices are likely to drop and investors entering the market to get less revenues.

In a position paper of January 2017 [12], the Polish Wind Energy Association (PWEA) argued that if market data on certificates of origin are rarely available, this not only makes it impossible to analyze supply and demand related to the quota scheme (including e.g. to spot risks of oversupply), but it may consequently also distort market operations and frustrate rational investment as well as regulatory decisions.

The specific Polish case of certificate oversupply turned out to be due to not only the lack of certificate market data. The quota size conditions, namely an amount of certificates similar over many years, also contributed to the certificate oversupply.

To raise certificate prices and thus energy prices for final consumption the PWEA therefore advocated increasing the obligation quota for the future years (in line with the Polish National Renewable Energy Action Plan) such that electricity rates for the average family would rise, but with an acceptable amount (e.g. some 2 % annually).

In 2013 the UK-based not-for-profit organization Sandbag, issued its 5th annual report on the Environmental Outlook for the EU ETS [13] in a time in which EU ETS allowance prices were (still) very low. The report thoroughly analysed the extremely low-price certificate market conditions and concluded that external shocks and a lack of quota stringency had led to the underlying allowance oversupply, with the ultimate generic effect that the introduction of low-carbon technologies was slowed down.

In a similar way, in 2015 Barcelona's Research Institute of Applied Economics (IREA) analysed if a supposed oversupply of allowances in the EU ETS market did have an adverse impact on the innovation on installations covered by the scheme. By analysing the number of patent applications filed at the European Patent Office (EPO) [14], they found that an oversupply of allowances indeed acts as a barrier to technological advancement. So, an oversupply of allowances may cause a quota-based instrument such as the EU ETS to lose part of its intended mitigation impact: in their innovation strategies firms do take certificate prices and price expectations into account {5}.

IREA therefore proposed a stricter cancellation regime of allowances, which would help put the instrument back on track. Furthermore, to make the market less vulnerable to external shocks such as the 2008 financial crisis, it was suggested to implement an allowance floor price providing a more predictable incentive. The level of such a price floor would have to be high enough to stimulate innovation and at the same time low enough to avoid crowding out of production and undue loss of competitiveness.

Similar issues as mentioned in the above cases could be expected to arise in future hydrogen certificate markets. That is why in order to increase transparency of, and enable data analyses on certificate markets, a transparent hydrogen certificate exchange platform is ultimately to be preferred over bilateral trading. A good example to show this is the Swedish-Norwegian electricity market[1], where the main brokerages publish bid-and-ask quotes publicly online. Also, as was argued already, establishing: an optimal and regulated price floor, strict cancellation of allowances, and dynamic quota obligation rules, would typically reduce market participants' risks. It would also: strengthen the certificates markets' resilience to external shocks; create the right conditions for stimulating innovation in different technologies; and prevent situations of oversupply of certificates.

3.2 High demand

At the opposite side of the risk of oversupply is the risk that too little investment threatens to be made to generate a sufficient number of certificates to fulfil the quota. In that case prices will rise ‘through the roof’ and the quota may not be met. Usually, it is expected that when there is a shortage in the market and the prices rise, investors see a chance to deploy new production capacities and the market prices will stabilize again. The shortage, in this case, will be only temporal and will be solved by the market.

However, also reasons for temporal high certificate demand compared to supply are seen, which probably will not directly convince new entrants to join. In the Swedish-Norwegian electricity certificates market just mentioned, for example, the demand for certificates is determined by total electricity consumption and changes in the quota requirements, whereas supply depends on the production of renewable electricity, so varies at the short term depending e.g. on weather conditions. Without market regulatory interventions this combination turned out to cause prices of certificates to be quite volatile on the short run [15]. Cases of relatively high certificate demand can, however, also occur on the longer term e.g. due to the fact that ‘lead times’ of investment in renewable electricity production capacity are typically long. Also price volatility can therefore last quite long.

Comparable certificate price dynamics can be expected on the future market of green certificates for hydrogen: because the potential production volumes of green hydrogen are often directly linked to the production of renewable electricity, certificate prices may react strongly to fluctuations in weather-dependent production profiles on the short term, but also on supply profiles determined by investment-lead-times on the longer term.

Furthermore, because it is difficult for investors to make projections of future certificate price changes, they typically have to make decisions under significant uncertainty [15]. For investment in hydrogen production capacity this may imply that technologies with lower fixed costs are prioritized, i.e. ‘blue’ rather than ‘green’ hydrogen.

In actual practise some cases happened in which the quota size was set overly ambitious given available options to comply so that surplus demand could simply not be met. For example in the UK, Italy and Flanders these overambitious targets in non-mature markets led to high certificate prices, and insufficient investment to comply with the quota in the initial years. Besides investor’s uncertainty, other barriers were seen preventing capacities to be deployed fast enough to keep up with the quota target, such as: administrative barriers, lead times of projects, grid capacity issues, or simply protests against onshore windfarms [8] [16] [17].

[1] The Norwegian-Swedish electricity quota market is discussed more extensively in D8.2 [4].

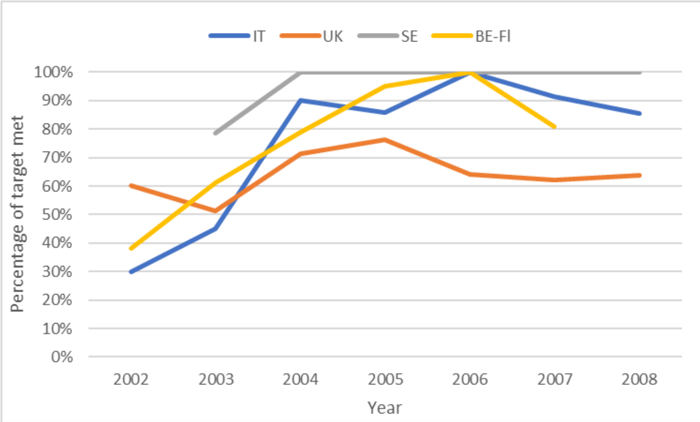

Figure 1 – Percentage of target compliance of quota obligations in Italy, UK, Sweden and Flanders, based on [8] [17]

3.3 Impact of certificate price fluctuations and uncertainty

An illustrative case study of the Swedish–Norwegian market [15] examined the peculiarities of electricity certificate markets and their prices: to get a better insight in the dynamics of certificate markets; to assess the impact of uncertainty and changing expectations on certificate prices; and to examine the repercussions of regulatory changes in the market structure on certificate markets. From the findings, the following points may be of interest too for future hydrogen quota schemes:

- In the particular case studied certificate price predictions pointed towards a gradual decline and ultimately to a zero price level as the certificate market would reach its intended end. Such development may generally clearly create a problem, because if the market perception is that certificates at some stage will be (nearly) worthless, this may already in an earlier stage create a downward price spiral in itself undermining incentives to be able to offer them on the market via overcompliance. In another study Ecofys 2014 [10] warned for the same adverse impact of considerable drops in certificate prices expected by market parties, e.g. when the market's targets are nearly met.
- It became clear from the study that due to generally small price elasticities even small changes in the market structure or in amounts of energy offered or demanded could already cause huge variations in certificate prices complicating the formation of proper price expectations. It is not unlikely that a similar volatility backdrop may show up in hydrogen certificate markets, and therefore should be taken care of to the extent feasible in such quota design.

Some preliminary conclusions to be drawn from the above case based observations therefore are:

First that in cases of threats of certificate oversupply and thus extremely low prices, periodic modifications, e.g. by gradually tightening quota schemes, may be needed in order to try to stabilize certificate prices during the market's lifespan. In addition, introducing the banking option, imposing minimum certificate prices, or mechanisms contributing to price floor levels may be considered (see next chapter for a more extensive elaboration). Such policies and measures may help preventing situations in which investors tend to not or no longer take incentives from the quota scheme to 'green' production seriously, or more generally situations in which the green entrepreneurs/net certificate sellers are punished via low certificate prices at the benefit of the non-green ones/net certificate buyers [1] [9].

Second that in the opposite case of high net demand for certificates, prices may skyrocket easily, even if supply-demand balances show limited shifts. This again may create problems up to the extreme case were parties try to frustrate the scheme altogether as being a non-realistic policy scheme that in their mind does not need to be taken seriously. But even if certificate prices turn just unexpectedly high unexpectedly fast, all kinds of not-wanted and unforeseen consequences may appear that policymakers would have preferred to prevent (see also the issue of windfall profits below). For such cases penalty payments for actors who fail to fulfil their obligations can help to offset the risks of exceptionally high certificate prices. Penalties then act as maximum limits to the certificate price, because parties covered by the quota scheme would always prefer to pay the penalty rather than a potentially higher quota price. In addition, just as with respect to floor prices, policy mechanisms can be considered supporting prices to not easily surpass some predefined maximum levels and creating undue windfalls.

Apart from the extreme cases discussed of unexpected very low or very high certificate prices, certificate prices may just suffer from being rather volatile and unpredictable. Such uncertainty may in practice discourage many potential investors to invest in the generation capacity required to meet the certificate's demand levels simply because risk premiums raise the required return levels too high to meet feasible financing conditions. There is empirical evidence that this in itself may sometimes lead to the unwanted side effect of windfall profits for certificate net sellers (for some examples related to electricity quota schemes in the UK, Italy, Sweden and Poland, see [10] ; see also [18] [19] [6] [20], and [21]). It is not easy to reduce quota scheme price volatility, but just as a clear certificate floor price and price cap, can quota policy flexibility and a long-term quota planning horizon for installations covered by the scheme be helpful in providing more certainty to investors [8].

3.4 Impact of few market participants and type of agreements used

In trading markets, liquidity enables market participants to trade in an easy way and in large volumes of transactions without a strong impact on prices (thereby lowering price volatility). In a liquid energy certificate market, buyers and sellers are able to find each other easily and the market price is transparent [22]. The more participants are active on a market: the more liquid a market becomes, the lower transactions costs are, and the more confidence there is in the market potential to service supply and demand. All this potentially increases incentives to operate on that market. This may again attract more participants and bring more liquidity to the market, etc. in a vicious cycle. So liquidity is important, also in green certificate markets, and it can positively affect the success of a quota scheme, but is something that may well be missing typically in the introductory stages of quota schemes [23].

Since in starting quota schemes, the amount of buyers and sellers is relatively limited and prices are uncertain due to their sensibility for (small) disruptions, individual market parties may prefer bilateral long-term agreements in this phase in order to provide stable conditions for themselves [22]. As prices in these contracts are agreed bilaterally, and so are not published, it is not known by others what prices are paid for certificates in these markets. Also, long-term agreements are typically made just once in a while and trade partners are often hard to find. All this results in a market with high asymmetry of price information, which may discourage potential new entrants to join [18] [22]. Moreover, the largest sellers and/or buyers will typically have a lot of market power via their bilateral trading, as they have access to the most market information. Therefore, without supportive measures to increase market transparency, there is little incentive for the dominant market participants to trade certificates via other types of agreements.

A more transparent channel to trade certificates, and therefore potentially beneficial for increasing market liquidity, is trading certificates via exchange platforms, as such platform provide an overview of (potential) buyers and sellers and real-time prices paid for the certificates [23]. Usually exchanges are being developed when the traded volumes in the market are substantial and when market participants support such a development because they perceive it to be advantageous for them to trade via an exchange platform.

Another type of channel to trade green certificates is via brokers, which are parties that merge, sell and buy offers for certificates, but will commission for their service a charge in return. Brokers can abuse untransparent markets by trading the certificates with very high margins for themselves. However, if there are multiple competing brokers in the market, or if brokers are obligated to publish historical information about average prices paid for certificates, abuse of market power by brokers can be reduced or ruled out completely. Brokers can play a significant role in reducing market transaction costs, as long as they are willing to operate efficiently [23].

Beyond the type of agreements used, another way to increase the market size and liquidity in a hydrogen certificate market is introducing wider regional or even international markets. But even then the necessary conditions for market liquidity must exist, including adequate transportation infrastructure, high supply and demand volumes and numbers of participants, and reliable and accepted schemes of hydrogen certification/standardization. Although for the voluntary electricity Guarantee of Origin system an EU wide market does exist, such markets are currently not seen for mandatory quota-related certificate markets in the EU. The only international example (according to the knowledge of the authors) of an international mandatory quota is the Norwegian-Swedish electricity quota. Although a wider market generally raises market efficiency and cost effectiveness, additional issues and complexities should be taken into account:

- The certification scheme should be standardized, accepted and work reliably in all participating countries;
- The risks of cases perceived as 'leakage of support' increase [8], for example if country A provides additional supportive measures to stimulate deployment, but country B purchases the corresponding certificates and claims the 'greenness';
- The complexity to predict certificate prices increases due to the increased variety in regional characteristics and legislations [8] [21];
- There is an increasing risk of a mismatch between physical and virtual claims, especially when infrastructure availability for international transport is limited: see also D8.2 'Assessment Admixing Schemes' [4];
- There may be more legislative uncertainty due to the larger number of governments involved that can adopt new rules and legislations [21].

3.5 The risk of windfall profits and technology-neutral quota schemes

Policymakers when introducing hydrogen or other energy use quota could feel strongly motivated to do so in a technology neutral manner. This way the choice of the underlying technology is left to the market, not to the less-informed policymakers themselves, guaranteeing according to the textbooks the best allocation and the highest level of efficiency. This probably also explains why in its December 2021 new 'Hydrogen and Decarbonised gas Market Package' proposal [24], the EU pushed for the introduction of a quota of 'clean' hydrogen, i.e. with at least 70% less CO2 emissions than those of natural gas, without any further indication as to with the help of which technology the 'clean' hydrogen was to be produced. Within this technology-neutral view that accepts 'clean' hydrogen still involving emissions there is a decision to base the amount, or the value of certificates received on the emissions caused during production, keeping the technology neutral character of the quota scheme.

The technology neutral quota approach, however, may yet have some adverse impacts, especially if, as in the case of hydrogen production, at least two (next to various so far minor other technologies) fundamentally different technologies can be employed to produce 'clean' hydrogen to fulfil the quota criteria, namely electrolysis with Renewable Energy Source (RES)-based power (the hydrogen of which is often labelled 'green'), or Steam Methane Reforming (SMR) of natural gas with Carbon Capture and Storage (CCS) (its hydrogen is often labelled 'blue').

A first adverse impact relates to path dependency of technologies, especially when they still are in their early stages of implementation. If a technology-neutral hydrogen quota is introduced, market parties will tend to first look for hydrogen accepted in the quota with the lowest production costs. This will almost certainly boil down to a concentration on hydrogen produced with the help of one particular technology. Production with the help of the dearer technology will then not get off the ground. The scaling up of the winning technology may, however, generate economies of scale and scope such that the competitive edge of that technology keeps growing, so that it gets increasingly difficult for the alternative technology to come off the ground. In the case of clean hydrogen evidence suggests that in such a battle 'blue' hydrogen will be the most likely winner because of its at least initially lower production costs (€37- €41/MWh, €1.20-€1.40/kg for blue compared to €70-€130/MWh, €2.30-€3.30/kg for green according to Gas for Climate [25] [26]). Consequently opportunities for 'green hydrogen to enter the quota market are undermined via the technology-neutrality of the quota scheme, and in fact chances for 'green' hydrogen to enter the scene may be getting worse and worse as time progresses because it will continue to be crowded out by the cheaper 'blue' alternative. If potentially the 'green' hydrogen technology would have the best perspective of ultimately becoming the lowest-cost option, the end result can become an economically suboptimal technology development.

A second adverse impact of technology-neutrality towards a quota scheme is related to the potential to breed windfall profits. In order to explain this, first the concept of 'producers' surplus' used for this case needs to be explained. This can be done with an example based on an quota for green electricity. A producers' surplus, as illustrated by [27] in Figure 2, is the difference between the cost of electricity produced conventionally and of 'green' electricity produced with the support of a public promotion mechanism (e.g. a tradable green certificate system). In other words, it represents the extra costs of getting electricity production green and thus the policy costs. Under competitive conditions this extra costs will eventually be borne by energy end users and transferred by them to the producers of green electricity. Obviously, the size of the 'producers' surplus' will differ depending on the types of technologies supported and the design of the support mechanism (e.g. quota size and whether technology-neutrality applies). The lower the so-defined producers' surplus of a quota scheme is, the smaller the transfer, and the easier it will likely be accepted by end users to 'go green' [8].

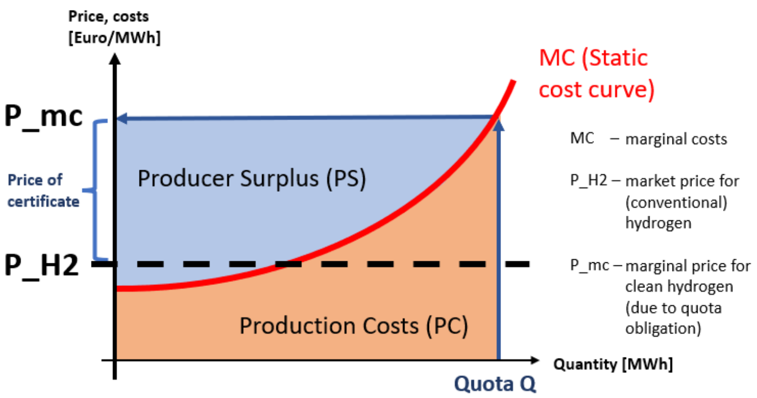

Figure 2 – Basic definitions of the cost elements for a mandatory quota scheme, based on [27]

Once a quota is specified on the basis of technology-neutrality of 'clean' hydrogen, the producers' surplus can be illustrated with the help of a so-called merit order curve illustrating how marginal production costs of clean hydrogen change as the production scale grows. Obviously for economic reasons first the lowest marginal cost technologies will be used to produce the clean hydrogen for the quota, followed by the next lowest cost option, etc. This sequence or merit order of marginal cost levels per technology implemented creates the upward sloping merit order curve, which, assuming that supply of hydrogen follows as soon as unit marginal costs are covered by the price of hydrogen, in fact represents the hydrogen market supply curve. The market equilibrium hydrogen price can be found on the point where the merit order-determined supply curve intersects the quota-determined demand curve. This equilibrium price level covers the marginal cost of the producer that just falls within the quota (the so-called marginal producer), but surpasses by definition unit marginal costs of lower-cost- or so-called intramarginal producers, who for that reason gain an extra reward or windfall profit beyond the returns needed to cover their marginal costs, a profit representing the so-called producer surplus. For a simple illustration relating to renewable electricity generation, see Figure 3. The figure shows the difference between a situation when the used technologies in the quota have small differences in marginal costs, resulting in relatively small windfall profits (see Figure 3a), and a situation when the technologies in the quota have large differences in marginal costs, resulting in relatively high windfall profits for the intramarginal producers (see Figure 3b).

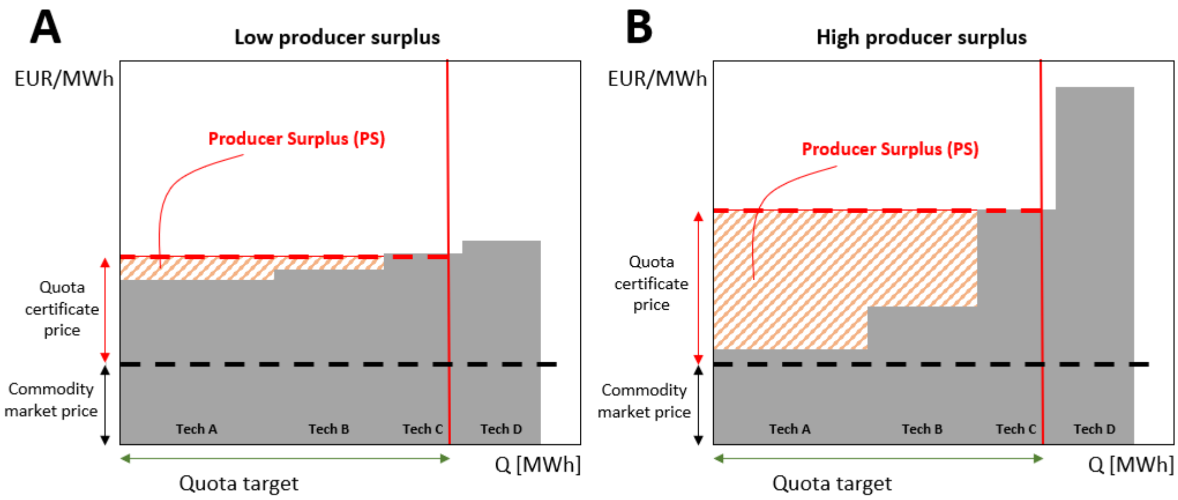

Figure 3 – Example illustrations for A) low and B) large producer surpluses in quota scheme markets, based on [7]

The producer surplus can be interpreted as a waste from a societal perspective because it essentially involves a transfer from the buyer of green hydrogen to the seller as result of the quota, that did not require any extra effort from that supplier. Because for the time being marginal production costs of blue hydrogen generally are assumed to be significantly lower than those of green hydrogen, such windfalls (referring to the situation of Figure 3b) will typically accrue to producers using blue hydrogen technology if green hydrogen is used to comply to the quota as well.

Any differentiation within a quota between various 'clean' hydrogen production technologies will be based on political decisions. As was mentioned before, with respect to hydrogen sometimes a distinction is made between so called 'blue' and 'green' hydrogen technologies. However, a complexity can be that 'turquoise' (pyrolysis) or 'pink' (nuclear) hydrogen technologies also enter the discussion such that one rather prefers a distinction between 'renewable' and 'low carbon' hydrogen. Measures to do this are described in sections 4.6, 4.7 and 4.8. Whatever quota categories one wants to distinguish obviously ultimately is a political discussion.

Another point of attention with respect to quota specifications is the differentiation of the quota in the course of time: for example, the shares of accepted volumes of 'blue' and 'green' hydrogen can be altered as time progresses depending on political preferences. The option to be able to adjust quota in the course of time is anyhow advisable because the merit order of marginal costs is not static and may without quota adjustment lead to unwanted technology shifts. To illustrate, let's focus on 'blue' vs 'green' hydrogen production technology, the possible production costs (generic, not specific for the Netherlands) of which during 2020-2050 have been projected in Figure 4 below. As the figure shows (under specific assumptions with respect to the future development of, for example, electricity, natural gas, CO_2-penalties and technology costs), production of 'green' hydrogen is projected to get gradually more cost-effective than that of blue hydrogen. However, green production routes are expected only to compete it in the near future at some 'best' production locations. For the average locations this possibly can take some longer but in the long run they are projected to be competitive as well. The figure also shows that for the natural gas price significantly impacts the costs of blue hydrogen production. The costs of the traditional grey hydrogen production route is not shown in this figure. Usually it is seen that the competitiveness of grey vs blue is affected significantly by the CO2 penalty prices. Hence, developments of multiple factors over time may affect the preferences whether to differentiate or not, and whether to decide if blue should be included in the quota or not.

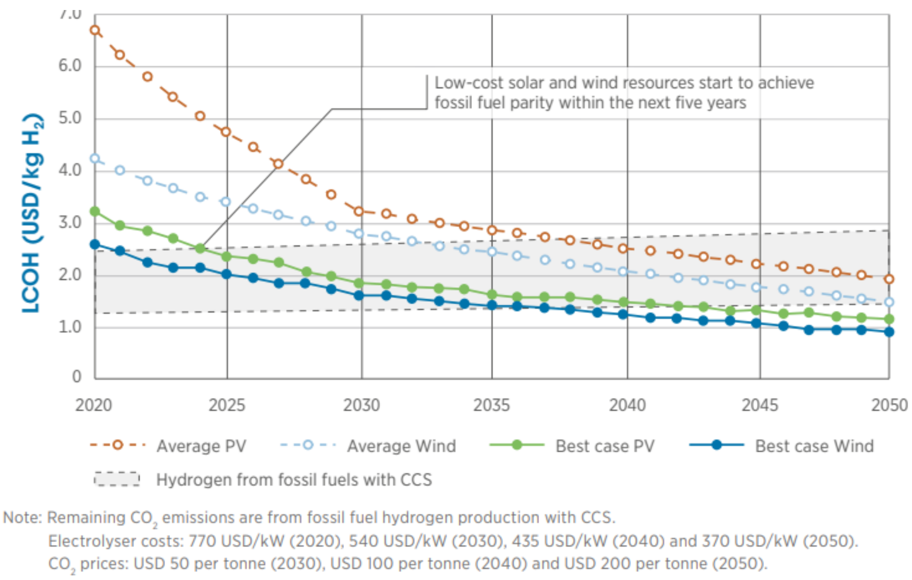

Figure 4 – Hydrogen production cost from solar and wind versus fossil fuels [28] Additional assumptions: Wind best LCOE 11-23 USD/MWh, load factor 47-63%, wind average LCOE 23-55 USD/MWh, load factor 34-45%, PV best LCOE 4.5-18 USD/MWh, load factor 27%, PV average LCOE 22-85 USD, load factor 18%. Fossil fuel cost range of 1.9-5.7 USD/GJ. Note: these are generic assumptions, assumptions specific for the Netherlands could differ.

3.6 Quota schemes and the condition of additionality

As soon as a 'green' hydrogen quota becomes operational, according to the definition of 'green' the quota must be filled with hydrogen generated from renewables-based electricity (RES-E). In a normal economic system the same RES-E, however, is also needed for all kinds of other purposes. To the extent that RES-E production capacity is fixed, at least on the short term, the additional demand for RES-E for quota purposes may therefore threaten to crowd out the availability of RES-E for other purposes. Insofar as such crowding out causes other users to start relying on fossil-based rather than RES-E-based electricity, the mitigation impact of the quota will be limited unless some market party needing RES-E will take responsibility for expanding RES-E capacity.

Because it is up to the political system to decide which party will have to pick up that responsibility, the choice is rather arbitrary, but may fall on the producers of green hydrogen, who then may only be allowed to use RES-E for green hydrogen production if they can proof that they have generated (or imported) the additional RES-E capacity for such production. From an economic perspective, it may be argued that there is no reason to put the burden of creating additional RES-E production capacity on just the shoulders of the producers of green hydrogen. Rather all RES-E users could be burned with this responsibility or typically those users the activities of which have the lowest impact on general welfare (which green hydrogen producers are very unlikely to be).

If and to the extent that a RES-E additionality condition would be added to a green hydrogen quota, the system gets more complicated in the sense that only those green hydrogen producers will be able to enter the market that have the financial capacities to, next to their investment in electrolyser capacity, also take care of investment in new RES-E capacity. Ways to administratively support such combined investment are joint tenders, corporate power purchase agreements or direct lines [29].

3.7 Impact of (lack of) available infrastructure for physical hydrogen transport

Another complexity of introducing a green hydrogen quota can be that market players covered by the quota obligation are physically unable to comply simply because the gas grid they are connected to cannot deliver it [30]. Because they generally cannot be held responsible for grid connections, a solution needs to be found to enable them to do comply, which – as extensively discussed in D8.1 [3] – can be to allow compliance via buying (and subsequently cancellation of) certificates. In other words, in such cases the option of 'virtual trading' via low- and zero-carbon hydrogen certificates may be able to bridge the gap. The buyer of the certificates may purchase them from a producer that somehow realized a surplus of green hydrogen beyond its quota obligation. In doing so the buyer will probably effectively pay the difference in cost between grey and green hydrogen (and contribute to the liquidity of the green hydrogen certificate market) [29]. The certificate enables the buyer to claim having fulfilled its quota obligation.

4. Expected impacts of potential mitigation measures

In chapter 3 various issues and possible mitigation measure have been discussed that may typically emerge in the initial stages of quota mechanisms. In this section the broader impact of such mitigation measures is discussed based on the literature and experiences in the past. Table 2 provides a brief overview of the main issues and potential measures that could mitigate them.

Table 2 – Overview of issues and potential mitigation measures

Issues / mitigation measure	Market transparency	Bank-/borrowing	Adaptable quota target	Min-/max prices	Market stability reserve	Technology banding	Bonus/malus	Carve-outs / sub-targets	Incl. existing capacities	Flexible subsidy approval
Mismatch in supply and demand		X	X		X			(-)		X
High certificate price fluctuations	X	X	X		X					X
High certificate price uncertainty	X	(X)	X	X	X	(-)	(-)		X	X
Diversity of stimulated technologies						X	X	X		
High windfall profits	(X)					X	X	X		
Unequal market power distribution	(X)								(X)	(X)

X = mitigation potential. (X) = possible mitigation potential. (-) = potential negative effect.

4.1 Market transparency

If markets are not transparent, buyers and sellers have no clear information on prices and may pay too much or get too little, or vice versa, whereby margins are captured by traders with more and better information. This may easily create unreasonable high margins for such traders thereby possibly frustrating the market process and adversely affecting market liquidity. Frei et al. [22] analysed several green power certificate markets (both voluntary and mandatory ones) to learn lessons about how the design of such markets could improve their liquidity. Three types of markets were distinguished:

1. Trading on an exchange: most trading takes place on one central exchange. (although an example in India was mentioned where trading of certificates took place at two open exchange platforms). Then it can relatively easily be regulated what type of agreements can be made (e.g. spot, forward, or long-term); prices can be made very transparent, and it is very easy to find potential partners for trade (high liquidity).
2. Trading via brokers. In these markets most trading finds place via brokers which are intermediate parties that take care of connecting sellers and buyers. As long as enough buyers and sellers demand for short-term and forward contracts, market price formation generally works out well. If brokers moreover publish their prices or bid-and-ask quotes (preferably also of long-term contracts arranged via the brokers), market transparency can be created as well.
3. Bilateral trading: In these markets a dominant share of trades is executed bilaterally, so between two parties without intermediaries. Mostly long-term agreements or own fulfilment of quota targets dominate in those markets. Due to the kind of trading, it is generally harder to find trade partners than in the above cases. Also potential new entrants are generally disadvantaged compared to established parties. Transparency of prices is typically low if not absent, since prices are often not published in cases of bilateral trading or own generation.

So, it generally holds that the more certificates are traded bilaterally and/or via long-term contracts, the more untransparent, illiquid and inefficient the market will be and the larger the risks are that the market power of larger established parties or traders will discourage new entrants to join. It is, however, fair to say that in actual practice individual market parties often choose in favour of long-term contracts in order to secure a more certain income over a longer period from their investment, especially when prices are uncertain and untransparent. To yet enable the market to become more liquid and transparent regulative measures can be taken (see also. Frei et al. [22]), such as: defining and supporting eligible trading channels; prescribing the disclosure of trade prices (e.g. via exchange platforms and brokers); defining eligible legal products such as spot and forward contracts; or regulating that all certificates should be sold/transferred at specific market platforms.

4.2 Banking and borrowing

Banking and borrowing are measures to increase the intertemporal efficiency of mandatory quota schemes [31]. Banking allows parties to transfer remaining certificates to their next years' obligation, if they already complied with their current years' quota obligation. Borrowing allows the opposite, i.e. to transfer certificates from current years' towards next years' obligation, when there is a shortage of certificates in the market. See Box 1 for examples of banking and borrowing in practice.

Box 1 – Examples of banking and borrowing

Banking

If without a banking option a producer of RES-E, company A, has, for instance, to cancel 1000 certificates in year *y*, but already cancelled 1000 certificates one month before year *y* ends, it clearly does not make sense to cancel more certificates than the quota prescribes. So, company A wants to sell the remaining certificates (that otherwise could expire) to other obligated market parties. However, when (most) other market parties already fulfilled their quota as well, there is no (or little) demand and the potential price may drop tremendously: company A will get no or hardly any revenues for its last month's RES-E production.
When banking is allowed, company A could transfer the remaining certificates to the next year, *y+1*. Assuming its quota is 1000 certificates in year *y* and 1200 in year *y+1*, and that it cancels 1100 certificates in year *y* (100 more than required), then it only has to cancel 1100 certificates in the next year(1200 minus 100 banked certificates).

Borrowing

Let's take the same example as used for banking, but now company A has cancelled only 900 certificates while it is obligated to cancel 1000 at the end of year *y*. In this case it would need to purchase another 100 certificates, but if there is a large shortage of certificates in this year, the prices may go 'through the roof' and obligated market parties may choose to pay penalties. If, however, borrowing would be allowed, company A could decide to only cancel 900 certificates in year *y*, while accepting the consequence that she needs to cancel 1300 certificates in year *y+1* (1200 plus 100 borrowed ones).

Allowing banking and borrowing is generally seen as a measure to reduce short-term mismatches in supply and demand in the certificate market thereby reducing short-term price volatility. Especially with production directly or indirectly depending on weather conditions, such as RES-E and renewable hydrogen, weather can be a major cause of unexpected production shifts and price volatility [32]. What the presence or absence of the banking and borrowing option empirically can do was for instance illustrated in a paper by Nagl [32]. He first applied an electricity market model without banking and borrowing. This resulted in modelling results of meeting quota targets by every year by deploying more and a larger mix of renewable power technologies, than in simulations with the help of model specifications including banking and borrowing. Moreover, without banking and borrowing the overall certificate prices were higher causing higher social costs for consumers than when banking and borrowing was included [32] [33].

In practice, as was, for instance, experienced in the beginning (2003-04) of the Swedish electricity quota obligation case mentioned earlier, heavy certificate price fluctuations can ultimately withhold new investors from entering the market, or may undermine quota fulfilment once certificate prices passed the penalty price level [10]. A certain level of banking and borrowing can then be helpful by allowing obligated market parties to spread risks due to the variance of weather conditions or otherwise thereby avoiding heavy certificate price volatility or severe price drops at year ends [32].

Practice also taught that when banking and/or borrowing is accepted, a maximum amount of allowed banked or borrowed certificates should be determined in order to avoid compliance with the help of borrowed certificates forever. Husveit et al. [15] showed for a single moment in time that the banking level would have been too high if the certificate price would be zero, or too low when prices were at the maximum price level.

4.3 Adaptable quota target or headrooms

Another potential measure to overcome mismatches in supply and demand is using adaptable quota targets; an example is a 'headroom' (see also next). The main reason why adaptable quota targets were introduced in some quota schemes in the past, was to reduce the risk of low and/or unpredictable prices for investors (or to guarantee a minimum price) [10].

A well-known example of a 'headroom' was implemented in the Renewables Obligation (RO) in the UK. Thereby a minimum and maximum target bandwidth was predetermined while the annual quota target was based (via a predefined calculation method) on the actual deployed capacities at the start of the year [34]. Although this annual target had to fall within the given bandwidth defining the desired pace of the transition, the bandwidth itself mitigated the impact of undue developments such as delayed projects or situations of oversupply on certificate prices. Moreover, by this flexibility the desired pace of the transition will not be violated, while at the same time market conditions can determine whether the annual quota target moves more towards the maximum or minimum target growth path.

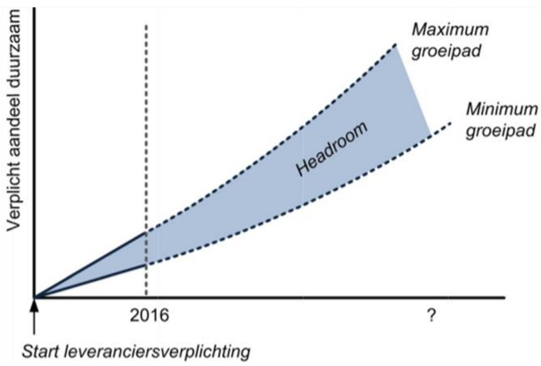

Figure 5 – Indication of a headroom: the actual target of each year should be between the minimum and maximum [34]

Another type of quota adaptation is based on minimum certificate prices: e.g. when certificate prices fall below a predetermined minimum level, the next years' quota obligation target may be increased. The underlying idea is that if there is a temporal certificate oversupply causing certificate prices getting too low for the green production projects to gain sufficient return on investment, then the adaptable quota target will shorten the period that this happens by increasing the demand for certificates in the next year. An advantage of this system can be that the deployment of green technology can be accelerated further when the market is ready for it, whereas with non-adaptable targets entrepreneurs can remain cautious to do so because of the risk that the existing capacities are already sufficient.

4.4 Minimum and maximum certificate prices

As was argued already, at the start of a quota obligation scheme, minimum and maximum certificate prices can be used to create a bandwidth for certificate prices. This bandwidth reduces the uncertainty of certificate prices in the initial years of a quota obligation by reducing price risks for potential new market entrants [34] and providing a cost-control function to obligated market parties. As the quota obligation scheme matures, the bandwidth can be broadened, ultimately leading to a mature market-based certificate marketplace. This section discusses ways to determine and guarantee minimum and maximum certificate prices.

In practice almost all quota obligation schemes include 'maximum prices' via a system of penalties in case of non-compliance. That is because it makes no sense for obligated market parties to pay more for a certificate than the penalty price of not complying [10]. Except from that also otherwise maximum prices can be introduced. In determining their level various perspectives can be taken:

- The maximum or penalty price is meant to protect obligated market parties against too high costs of compliance;
- The maximum or penalty price should surpass the expected certificate market price; otherwise there is no incentive to fulfill the quota and there will not be additional investments in renewable capacities [8].

Penalty levels do not have to be fixed. In the Swedish electricity quota scheme mentioned the penalty level was determined ex post by the actual certificate price, i.e. being 150% of the average certificate price during the year [34]. Through that practice the penalty price loses most of its costs-control and maximum price cap function [10], but it guarantees that purchasing certificates is always less costly than not complying. This could be interpreted as beneficial for investors, but a risk for end users [34].

Another way of enhancing the willingness to comply is using a so-called 'buy-out fund' (used in the UK renewables obligation scheme). This fund channels the total budget of annually paid penalties to the complying market parties thereby increasing their willingness to comply, as otherwise the money spent on penalties will go to competitors [34].

Minimum certificate prices are less commonly used in quota obligations than maximum prices. Minimum prices guarantee a minimum price received for certificates, comparable to subsidies [34]. There are multiple ways to (partially) guarantee a minimum price. One known system with full price guarantees was the Swedish electricity quota, which guaranteed minimum prices in its starting period from 2003-2007 [35]. In this system, for certificates that could not be sold during their shelf life, there was the option to cash them in against a predefined tariff with the government. The minimum price level was lowered every year until it was phased out in 2008. A minimum price level should be chosen very carefully, because if too high it may lead to excessive deployment and costs for those that have to buy the certificates. In the multiple electricity quota systems operated in Belgium, it was the grid operators, not the government, who were obliged to purchase the green certificates, sometimes against the minimum prices, that were moreover also even differentiated based on production technologies used [36]. However, this seemed to be a specific case of public parties being obligated to act as buyers.

Other policy options to (partially) guarantee a minimum price, some of which have been discussed already, are: the 'headroom' (the quota target increases when the certificate price drops below a predefined level), a market stability reserve (the government purchases certificates against a predefined minimum price), or having the option to switch between OPEX subsidies and quota certificates.

4.5 Market stability reserve

The market stability reserve (MSR) is a mechanism within the EU ETS to stabilize certificate (or in the case of the EU ETS, allowance) prices. Via such a mechanism credits or certificates will be purchased when their prices drop below a predefined level. On a later moment, preferably when the certificate prices are high, the purchased certificates are released onto the market again. The minimum price level, maximum reserve volume, and release procedure are components of the mechanism that obviously have to be designed very carefully.

The MSR intentions (to stabilize certificate prices and overcome temporal mismatches between supply and demand) are comparable to those of the 'banking' mechanism. An important difference, however, is that in a MSR a price level can be set determining when certificates are purchased via the mechanism, whereas in a banking system it is optional for obligated parties whether or not to buy additional certificates for being banked. Also, the MSR guarantees a minimum certificate price, up to the point at which the maximum volume of certificates in the reserve is reached.

4.6 Technology banding

Technology banding is a measure towards quota obligation schemes that aims to stimulate a variety of technologies, and to overcome potential windfall profits, as described in section 3.5. This can be desirable, for example for technologies that have lower TRL levels but are expected to have high potential, or if one simply wants to get to a multiple mix of technologies. Technology banding is applied by using different multipliers determining the amount of certificates to be received per technology [10]. In various renewable electricity quota obligation schemes through technology banding wind energy received a higher multiplier than biomass-based energy, just to overcome that only electricity from biomass would be supported. Also, technology banding was sometimes used to stimulate the development of smaller localized generation projects, in order to increase the variety of projects. Technology banding is often compared with carve-outs, as they both have the same aim in quota obligation schemes. By implementing such measures, a backdrop may be that the technology-neutral character that quota obligation schemes can have gets lost. The main advantages of technology banding (as compared to carve-outs), however, are that:

- it stimulates to get a more diverse portfolio of generation technologies [37];
- by differentiating multipliers potential windfall profits can be reduced or even prevented [37];
- the certificate market remains one market (unlike when using carve-outs) with homogeneous tradable certificates;
- multipliers can easily be adapted enabling flexible implementation [37].

The main concerns with respect to technology banding are that:

- it raises the issue how and by whom to decide on what grounds what technologies get higher multipliers than others, and, more generally, lowers the market-conformity perception of the quota instrument [37];
- it requires solid estimations of the cost developments of different technologies to set the multipliers right [10]. If this fails the playing field between technologies gets unequal [37];
- it breaks up the relation between the amount of certificates cancelled and the actual amount of renewable/low carbon energy generated and/or used [16]. It consequently becomes less clear if a certain obligation level will e.g. lead to a potential RES target;

- it may make markets more complex and certificate prices more difficult to predict [10] [37].
- the perceived regulatory risk for investors may increase, because governments can adapt multipliers directly and relatively easily [30]. This can increase risk premiums required by investors and thus certificate price levels [30].

In the past technology banding has been mostly implemented to ensure that a portfolio of multiple technologies was stimulated, or that less mature but promising technologies would have a better chance to be deployed [10]. Sometimes multipliers have been based on related CO_2 emissions. For example, as the CertifHy label proposed [38]), the multiplier for 60% reduced low carbon hydrogen could be 0.6, for hydrogen with 90% reduced emissions 0.9, and 1 for carbon neutral and renewable hydrogen. This creates cost advantages for renewable and carbon neutral hydrogen, while maintaining the technology-neutral character of the obligation.

4.7 Bonus/malus

Bonus/malus is a potential measure very comparable to technology banding, and therefore discussed very briefly. In this system, producers of the more cost-effective accepted technologies pay a 'malus' (i.e. a fee) for every certificate that is issued. The relatively more expensive technologies receive a 'bonus' (i.e. a fee) for every certificate that is issued [34].

The effect is similar to technology banding: the cost differences between the technologies that can be used to achieve quota compliance is reduced. Also here, the bonus or malus fees for every technology should be determined very carefully. Thereby, similar advantages and disadvantages as the technology banding instrument are seen for bonus/malus. However, the main advantage of bonus/malus is that the relation between the amount of certificates cancelled and the actual amount of renewable/low carbon energy that has been generated and/or used remains intact. On the other hand, a new issue is to what extent the amounts of money paid and received for bonusses and maluses should be in balance, and if so how to achieve this. Moreover, a bonus/malus system has never been implemented in practice yet [34].

4.8 Carve-outs or sub-targets

Another way to, even more than technology banding or bonus/malus, secure that multiple types of technologies are deployed and supported, is introducing carve-outs or sub-targets. This means that an additional target is set for a specific, or specific set of technologies, in order to ensure that (multiple) technologies are deployed [10], or that deployment of certain technologies will be limited in the overall portfolio of supported technologies. For example in the Dutch fuel blending obligation based on RED, there is a minimum target for so called 'advanced' biofuels to be deployed, and a maximum target for 'traditional' biofuels that every obligated party can use for compliance. These sub-targets are separate targets that should be complied with, besides the overall quota obligation.

Introducing quota carve-outs or sub-targets by definition implies that the certificate market will be segmented. Instead of having one obligation, obligated market parties have two (or more) obligations: compliance to the full target as well as to the sub-target (see also example in box 2). This will most likely result in different prices for certificates used to comply with the full target (based on supply and demand of all accepted technologies) on the one hand and certificates that also count for compliance with the sub-target (based on supply and demand of those specific technologies) on the other hand.

Box 2 – Example of certificate market without and with the introduction of sub-targets

No sub-target included

Company A is an obligated market party that uses hydrogen and is obligated to cancel low-carbon hydrogen certificates for 10% of its hydrogen used. Let's assume that low-carbon hydrogen produced by Steam Methane Reforming (SMR) and Carbon Capture and Storage (CCS) has lower costs to produce than RES-based hydrogen, and that only these two technologies will be distinguished and both accepted. If there is enough SMR+CCS capacity to fulfill the demand of all obligated parties, it is likely that only this technology will be used for compliance since it has the lowest costs. If, however, not enough SMR+CCS capacity can be employed to fulfill the certificate demand of all obligated parties, more costly renewables-based hydrogen production technologies will also have to be deployed leading to overall (so, also for company A) higher certificate prices, but also to windfall profits for investors in SMR+CCS.

Sub-target included

If company A would again be obligated to cancel 10% low carbon hydrogen certificates, but now of which 5%-points should specifically be based on RES-based hydrogen, then company A has will exercise demand for renewable hydrogen to the amount of 5% of its total volumes. The equilibrium certificate price of this type of technology is expected to be higher than that of hydrogen certificates based on the SMR+CCS technology. So, for the leftover 5% of the overall quota, company A will choose for the cheaper certificate. In other words different prices will be paid for different types of certificates.

The main advantages of carve-outs or sub-targets are the following:

- Carve-outs guarantee (except from the situation of non-compliance) that specific technologies will explicitly be supported [10] [37];
- With careful segmentation windfall profits can be contained. This will, however, be more difficult the larger differences in relevant technology costs are;
- Compared to technology banding, the certificate prices remain better predictable and the actual targets keep representing the share of desired technologies deployed [10]. For example in the case of technology banding MWh/GJ of certain technologies count double or half, the volumes used or produced to comply to the quota depend on the technologies that are chosen to be deployed (if the target represents 100 certificates, 200 of technology A can be used/produced with multiplier 0.5, or 100 of technology B that has multiplier 1).

The main disadvantage of carve-outs or sub-targets is that certificate markets become segmented, which may reduce liquidity in one or multiple of the segmented markets [10] [37]. Also, when the certificate market is divided in multiple segments, risks of unequal distribution of market power and (temporal) mismatches in supply and demand are higher [10]. When considering introducing carve-outs, the impact on e.g. the potential number of market players and expected volumes of certificates traded via long-term contracts should therefore be assessed beforehand carefully to see if market liquidity remains acceptable [37]. For instance, in the Australian electricity quota obligation case mentioned earlier, due to the large share of certificates sold via long-term contracts (±80%) market liquidity was already low. Introducing carve-outs, however, did not result in a further reduction [37].

Both technology-specific sub targets or bands can be implemented to reduce the total producer surplus, which could result in windfall profits for some cheaper technologies or even outcompete other, new technologies with potential, completely [8], as described in section 3.5. This can easily be demonstrated by the indicative supply curves represented in Figure 6.

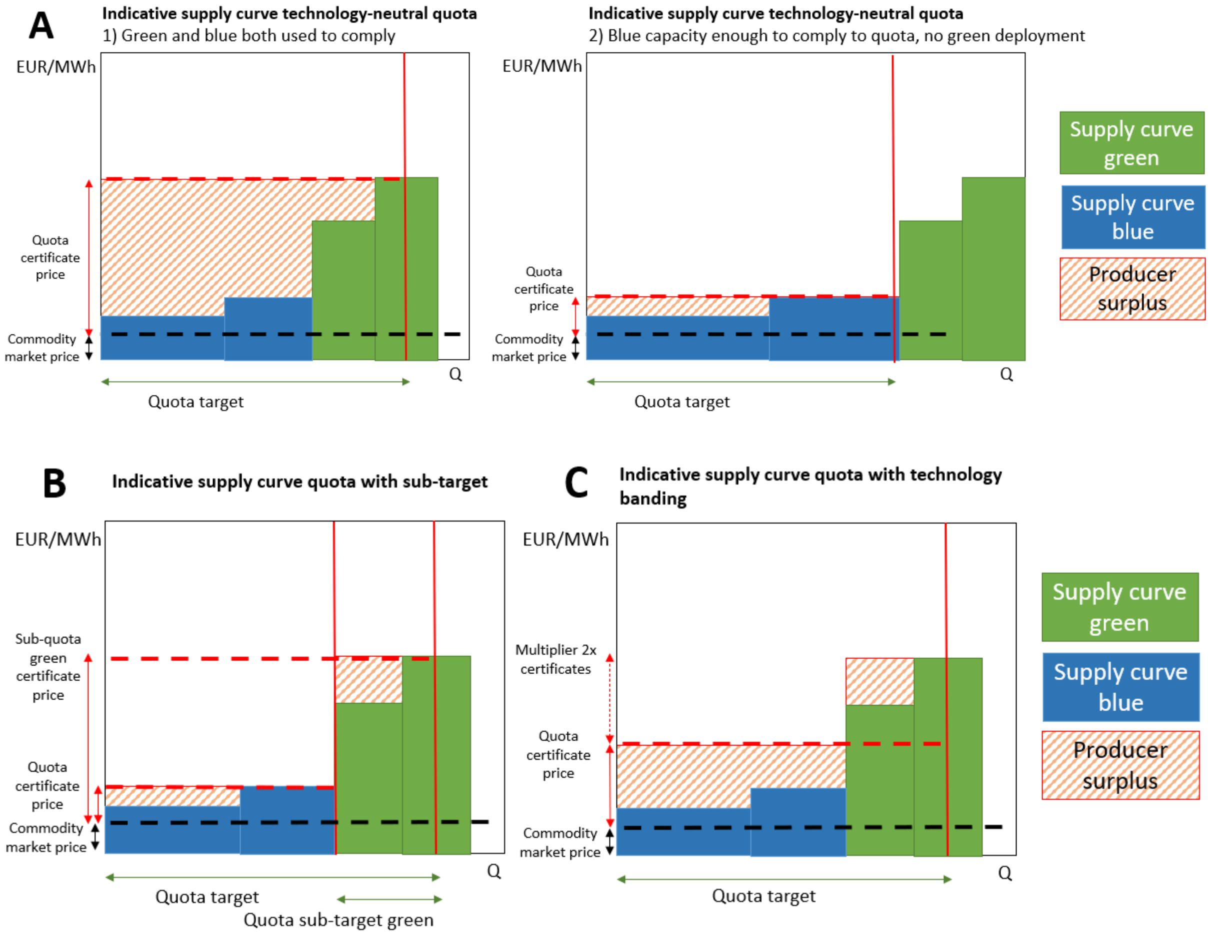

Figure 6 – Indicative quota supply curves showing the impact of A) a technology-neutral quota and B&C) a quota obligation including technology specific measures on the producer surplus

In Figure 6a the potential supply curve of a technology-neutral quota is shown indicating the risk 1) of high producer surpluses for blue hydrogen producers, if green hydrogen is also used to comply to the target, or 2) that green hydrogen capacity will not be deployed and stimulated at all because enough blue hydrogen production capacity can be established to fulfil the quota. Figure 6b shows the same indicative supply curve for a quota but now with a sub-target for green hydrogen. Now the producer surplus is reduced by the imposed distinction in prices paid for certificates generated via the different technologies. Figure 6c shows the impact of the technology banding option on the producer surplus of blue hydrogen producers. This surplus is now also reduced by the measure that the more expensive (e.g. green hydrogen) technologies receive more certificates for every MWh of hydrogen (or less expensive technologies receive less certificates) than if less expensive technologies (e.g. blue hydrogen) are used. Both policy options to mitigate producer surpluses - sub-targets and technology banding - can already be used as soon as the quota implementation starts.

4.9 Including existing capacities in the quota scheme

When the Swedish electricity quota scheme mentioned before started, existing capacities deployed in a predetermined period were allowed to join the quota scheme as well. The reason why was that this would boost the number of participants and liquidity in the early phase of the certificate market [10]. There are, however, two main points to be taken into account when considering to allow such an option. First that there is existing capacity available. The situation of Sweden was such that one already produced renewable electricity for a longer period with the help of hydropower plants. Second, existing production capacities should have no cost advantages compared to the potentially new deployed capacities, because this would harm the stimulation of additional deployment (typically one of the goals of such a scheme). For example, if existing capacities are already receiving other types of support such as subsidies, then this should not lead to a unfair competition with new projects that do not receive similar advantages.

4.10 Start the certificate market with a temporary subsidy scheme

In the literature, including what was already included in D8.1 'Admixing literature review' [3], it is argued that different types of support schemes can be optimal in different stages of technology maturity. For example, price-based mechanisms such as feed-in tariffs and premiums are generally believed to be the preferred option for promoting emerging technologies since the critical factor, risk, is reduced by the guaranteed revenues. When the market liquidity of the certificate market increases, the general belief instead is that volume-based instruments such as quota schemes may get more appropriate [11]. Leguit et al. [39] therefore specifically propose an initial subsidy phase to prepare the market for a gas blending obligation; they also propose that projects that have successfully applied for the subsidy scheme could not switch to (receiving certificates for) the quota scheme in a general sense.

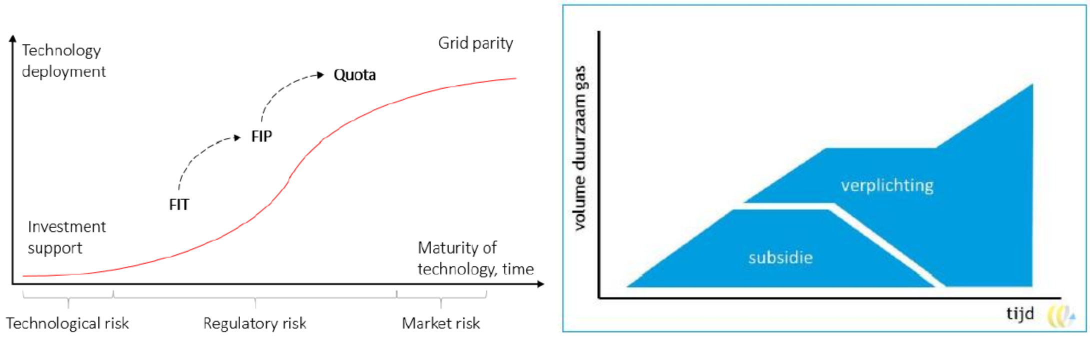

Figure 7 – The fitting support schemes at various stages of development [11] and initial subsidy scheme to start quota [39]

On the other hand, giving the opportunity for the initial, subsidized projects to switch between obtaining a subsidy or quota-allowed certificates (for example per production batch or per year) could give some advantages: that it can increase market liquidity from the start of the quota; that it sets an indicative certificate price from the start (based on the subsidy levels); and that projects where one can choose between obtaining the subsidy or quota certificates may act as a buffer for quota mismatches between supply and demand. A similar approach has been chosen in the Netherlands SDE++ subsidy scheme where eligible biomethane production projects are able for every batch produced to choose between either receiving Guarantees of Origin (GoOs) with a note of being subsidized (with SDE++ subsidy), or to receive GoOs with a note of not being subsidized enabling them to issue certificates that they can sell. These certificates are then typically used by fuel suppliers to receive HBEs which is why they are prepared to pay for the certificates. Via this choice duplication of support measures is prevented.

The latter principle is also likely to be reinforced in the upcoming Netherlands' hydrogen support mechanism via some very specific preconditions to align the scaling-up of a subsidy (such as through SDE++ or a comparable scheme) with the quota obligation. In preparing for this the following notions are discussed:

- It should be mentioned on future hydrogen GoO certificates if the represented volume received public support or not; this is also mandatory for GoOs according to RED II;

- Subsidies and quota obligations should face comparable criterions such that conditions are similar;
- The subsidy should not lead to unfair competition, and therefore in principle only close the so-called unprofitable gap and not include support of the investment/CAPEX, as this combination would lead to unfair competition (and potential windfall profits) in the quota obligation with projects that did not receive a similar investment subsidy (only if there are foreseen very large decreases in investment costs of the technologies, a CAPEX subsidy lower than the expected cost reductions upon the start of the quota obligation could be accepted);
- A maximum eligibility capacity level can be imposed on projects applying for scale-up subsidies to increase the number of projects developed and market liquidity once the quota scheme starts.

Example of how temporal scale-up subsidies can move towards a quota obligation market

To illustrate how a scale-up subsidy can be used to move towards a well-developed quota obligation market, see Figure 8 and following illustrations.

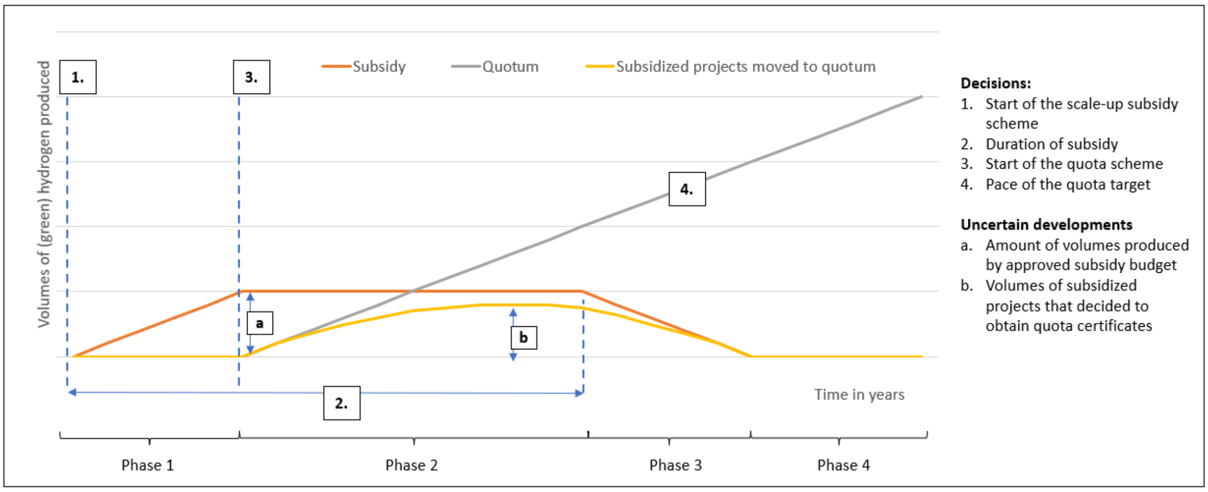

Figure 8 – The different phases of quota obligations development when using scale-up subsidies

In the first phase initially no actual capacities exist; initial capacities are only built up thanks to scale-up subsidies stimulating investors to invest in (scaling up) electrolyser projects. These early projects may have a demonstration and learning character and are likely to contribute to future higher efficiencies and lower costs. Figure 9 illustrates a stylized supply curve, where each section of the curve represents a group of similar subsidized projects. The blue arrow shows the total volumes that will be produced given the subsidies; the red arrows represent the level of subsidy for each (group of) project(s).

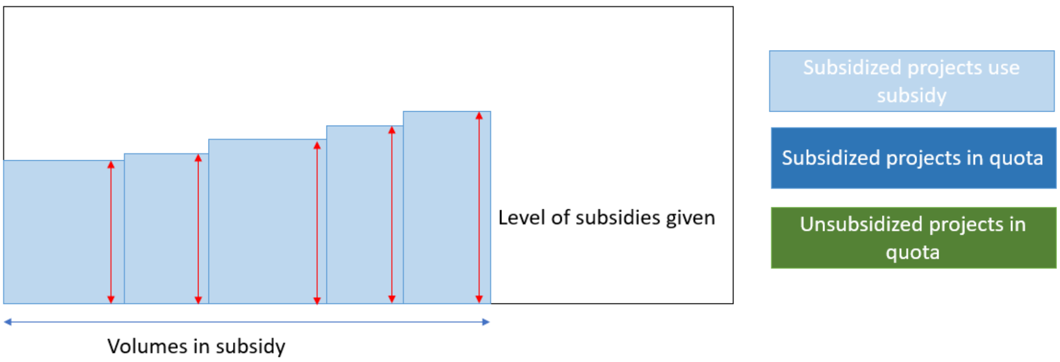

Figure 9 – Example supply curve before quota obligation starts (corresponding to phase 1 in Figure 8)

In the second phase (see Figure 8) the quota scheme will start. It is likely that subsidized projects will, if that option applies to them, move to the quota scheme when the expected certificate prices are higher than the subsidies they expect to receive. The complexity for them is, however, that due to the learning aspects of the initial phase new competing investors can also enter the quota scheme which will affect certificate prices. So, as soon as the quota scheme sets off, it is unclear how certificate prices will develop (the yellow line in Figure 8). That explains why it is likely that some of the new investors will wait joining the quota scheme to see what certificate prices will do, and that initially only the most cost-effective projects owners will move to the quota mechanism. Figure 10 illustrates how this move affects the quota certificate price.

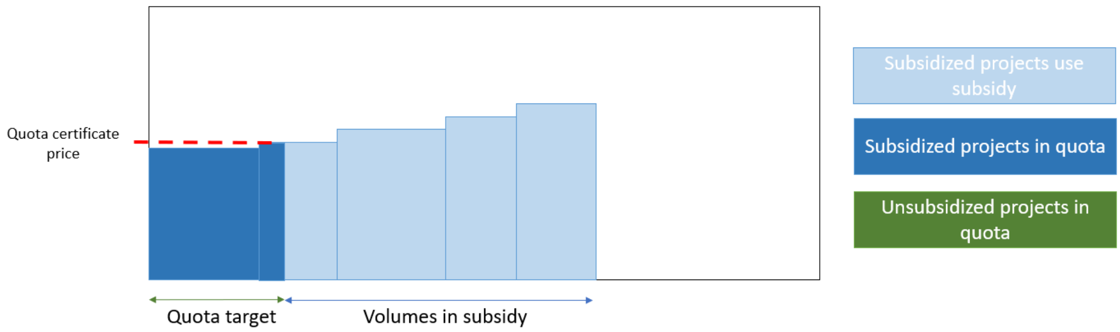

Figure 10 – Supply curve at the start of the quota scheme (corresponding to start of phase 2 in Figure 8)

Once the certificate price is set by the first projects and proven to be relatively stable, entering the scheme is likely to become more attractive for other potential entrants. Three scenarios can be distinguished describing how much (previously subsidized) investors will join the quota scheme and how much other new projects may be initiated (see Figure 11). In situation 1 no new investors will enter the market as the quota size increases except from investors in the (less cost efficient) subsidized projects, so that certificate price will rise. Since some investors leave the subsidy scheme, the subsidy costs for the government will decline. In situation 2, new (non-subsidized) entrants do actually fill the gap in the certificate market caused by the increased quota target. In this case, the quota certificate price and amount of subsidies paid will remain the same. However, the total volumes of (green) hydrogen produced increase. In situation 3, because the certificate price is perceived as attractive, more new investor volumes may enter the market than the quota rises. In this case, investors in subsidized projects that had entered the quota scheme will decide to move back to the subsidy scheme so that the amount of subsidies that has to be paid also rises again. Because the production cost level of the most competitive project under the quota regime is now lower again, the certificate price will drop. In fact, the flexibility of projects to join or leave the quota scheme will act as a buffer mechanism stabilizing the certificate market.

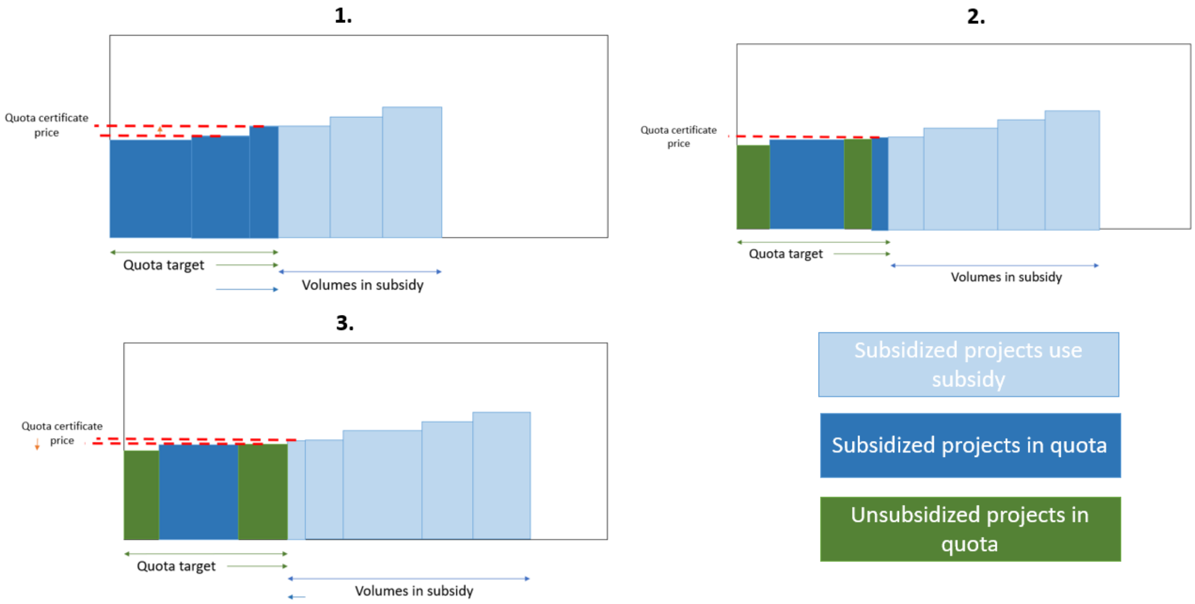

Figure 11 – Example supply curves for quota obligations including a scale-up subsidy mechanism (corresponding to phase 2 and 3 in Figure 8)

The more the quota target level increases, and the more subsidized project will be at the end of their duration (see phase 3 in Figure 8), the more the certificate market can be left free to become a mature market without control mechanisms (see phase 4 in Figure 8). This process is also illustrated in Figure 12. The red, yellow and grey lines in the left figure represent the deployed volumes of (green) hydrogen per type of project (e.g. projects using the subsidy scheme, initially subsidized projects that moved to the quota scheme, and unsubsidized projects under the quota scheme) and will differ depending on who joins the quota scheme. The right graph in Figure 12 represents the temporal bandwidth of volumes that can be deployed by allowing (subsidized) projects to obtain either subsidy or revenues from the quota obligation. The maximum path follows if no subsidized projects move to the quota scheme and the minimum path if all subsidized projects move to the quota scheme.

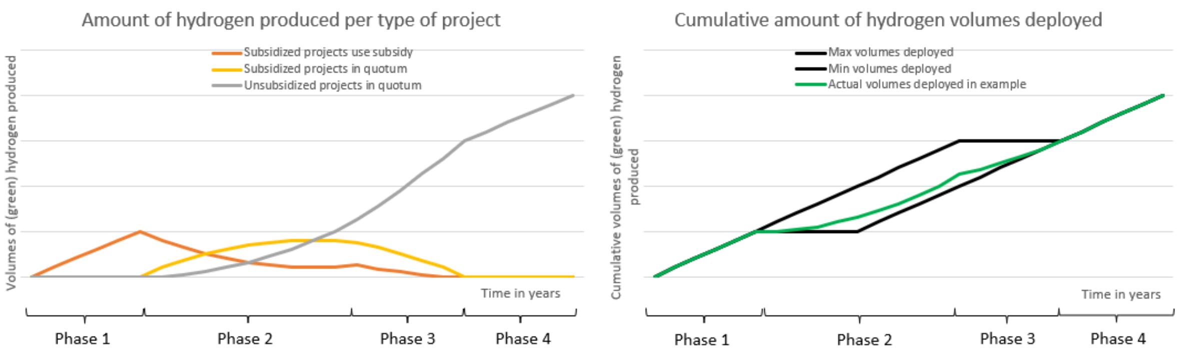

Figure 12 – (Example) representation of the cumulative and categorized developments of deployed hydrogen volumes

5. Reflection and implications for hydrogen quota obligation schemes

The goal of the European Green Deal [40] of making the European Union (EU) climate neutral by 2050, demands natural gas to be phased out in the medium to long run as energy carrier and feedstock [41]. While electrification sometimes offers a way to replace natural gas in some of the end-uses where it now dominates, this replacement of gaseous energy molecules by electrons may not be technically possible nor the most cost-effective solution is some specific other applications notably in industry and heavy transport. The latter raises the pressure to develop markets on which serious volumes of carbon neutral gases will be available; carbon neutral hydrogen is seen as one of the prime candidate for filling this supply.

In fact there are multiple ways of greening the gas system, such as substituting natural gas by biomethane, by methanation, or by the low-carbon or eventually carbon neutral hydrogen mentioned. Then again, low carbon and carbon-neutral hydrogen can be produced in a myriad of ways, for instance: from biomass, from fossil fuels in conjunction with carbon capture and storage or utilization (CCSU), or from water electrolysis (via so-called Power-to-Gas (PtG) technologies) provided the electricity used in the process itself originates from a low-carbon power source. In 2020, the European Union issued its own hydrogen strategy [42], and stated in the Green Deal's hydrogen factsheet that hydrogen will play a key role in reducing emissions in hard-to-abate sectors, particularly in industry and transport [43]. In some of the more recent 'Fit for 55' proposals, mandatory blending of hydrogen as a strategy to move forward received serious attention, as can be illustrated with the help of following three proposals:

- Proposed RED II (2021/0218) [1], article 22a:

  ''Member States shall ensure that the contribution of renewable fuels of non-biological origin used for energy and non-energy purposes shall be 50% of the hydrogen used for final energy and non-energy purposes in industry by 2030.'' (excluding *''hydrogen used as intermediate products for the production of conventional transport fuels.''*)

- Proposed RED II (2021/0218) [1], article 25b:

  A sub-target for RFNBOs used for transport is introduced: *"…, and the share of renewable fuels of non-biological origin is at least 2.6% in 2030."*

- Proposed ReFuel EU (2021/0205) [2], article 4 and annex I:

  "Aviation fuel suppliers shall ensure that all aviation fuel made available to aircraft operators at each Union airport contains a minimum share of sustainable aviation fuel (SAF), including a minimum share of synthetic aviation fuel in accordance with the values and dates of application set out in Annex I." (*"From 1 January 2030, a minimum share of 5% of SAF, of which a minimum share of 0.7% of synthetic aviation fuels."*)

Currently (start of 2022), renewable hydrogen technologies are not yet mature enough to compete with traditional energy sources, despite the current carbon price levels that elevated strongly during the last years to levels approaching euro 90/tCO2 [44]. As a result, member states, such as the Netherlands, are looking to ways to speed up and scale up the development and use of low-carbon hydrogen and its derivatives. Instruments that are already used to stimulate the deployment of renewable energy sources (RES) in the electricity sector, such as feed-in tariffs or quotas with tradable certificates, may obviously be modified to be also used for supporting the production and use of carbon neutral hydrogen.

The most critical success factors for new hydrogen quota schemes

The above analysis of the feasibility and design issues of possible hydrogen quota schemes has been carried out against the policy background sketched in this section. But what do seem to be the most critical points to consider when designing new quota schemes? We believe that the three points that can be considered the most crucial success factors in practice when implementing a new quota obligation for hydrogen are the following.

1. Market transparency. This is one of the key characteristics to be able to successfully develop towards a liquid and optimized certificate market. In multiple experiences with certificate markets, one could notice that in the early stages most of the certificates were traded via bilateral agreements, so that the actual market functioning and certificate prices remained a black box. If a carbon-neutral hydrogen quota scheme is to be implemented, it seems highly recommendable to take this as one of the key points of attention. Some sort of price disclosure should be stimulated or even made mandatory, for example hourly prices from brokers and exchange platforms trading the certificates per type of product (e.g. spot, short-term, forward and long-term products). As described in 3.4 and 4.1, disclosure of price information can also reduce market power of participants based on information asymmetry. Moreover, in similar quota practises long-term contracts clearly contributed by their risk-mitigation impact to the willingness to invest, especially in the very first stages of a quota schemes. It, however, also has become clear in practice that as the market starts developing towards a more mature and liquid market, short-term trading and exchange platforms can also be extremely helpful in getting there. Some examples seen in practice how market transparency can be stimulated are: to provide support for a well-designed exchange platform in the beginning of the scheme, to mandate brokers to publish general information on the traded volumes and average traded prices or, in the most extreme form, to enable certificate trading only on a predefined exchange platform of the government [22].

2. Since it takes time for upcoming certificate markets to develop into a well-balanced certificate market, investors and obligated market parties need to be protected against large fluctuations in and general uncertainty about certificate prices, especially in the early phases of quota schemes. In other words, measures need to be taken to deal with temporal mismatches between supply and demand, and minimum and maximum certificate prices should preferably be (partially) guaranteed. It doing so, it is important to recognize the two-sidedness of (temporal) minimum and maximum prices. If, for example, a maximum price is guaranteed, consumers are partially protected but producers are limited in their profits, and the opposite holds true for a minimum price. In chapter 4, multiple mitigation measures have been described that may prevent market disruptions in the early stages of the quota scheme from happening:
    a. A maximum price can be guaranteed via a fixed penalty to be paid at non-compliance of the quota (instead of, for example, a penalty of 150% of the average certificate price). A (partially) guaranteed maximum price can be achieved either by a so-called Market Stability Reserve mechanism releasing certificates when the price exceeds a predetermined limit (note that this option is limited as it can only put downward pressure on prices as long as the capacity of the reserve is sufficient), or by an adaptable quota target, e.g. only lowering the next-year's target if the certificate price exceeds a predetermined limit. Also in the latter case the options to adapt the quota targets may be limited to the extent that they collectively have to meet the long-run overall quota target.

b. A fully guaranteed minimum price results if the government or any other public authority fully guarantees to pay a minimum fee for 'leftover' certificates at the end of the year. A partially guaranteed minimum price can be ensured in similar ways as the maximum price, i.e. by a Market Stability Reserve mechanism or via an adaptable quota target. A third option is for (a share of earlier) projects to be able to fall back on a subsidy scheme if certificate prices drop below a specific level (see also 4.10).

If a fully guaranteed minimum price or a Market Stability Reserve mechanism is installed, those responsible for their execution have to also install a monetary buffer in order for always being able to comply with the guarantees. If public money is used for this, a delicate political issue may be how and by whom this is financed. Policy measures to mitigate certificate price volatility are, for instance: banking and borrowing, a 'headroom', or the provision of transparent price and market information. An overview of the various policy measures to stabilize certificate markets is provided in Table 3.

Table 3 – Overview of policy measures to stabilise certificate markets

Minimum/ maximum price	Guarantee (full/partial)	Measure
Maximum price	Fully	Fixed penalty price
	Partially	Market Stability Reserve
		Adaptable quota target
Minimum price	Fully	Minimum fee price
	Partially	Market Stability Reserve
		Adaptable quota target
		Flexible subsidy scheme
Remaining price stability measures		Banking/borrowing
		Headroom (referring to UK RO)
		Transparent market information

3. Including both low-carbon and renewable-based hydrogen. The last key point relates to the support of both low carbon and renewable hydrogen. It has been argued in the literature that if low-carbon hydrogen is accepted next to 'green' hydrogen to comply with a hydrogen quota obligation, it is likely[2] that without additional measures no or little 'green' hydrogen capacity will be deployed due to lock in effects (see also 3.5). To the extent that the development of 'green' hydrogen is seen as desirable in terms of the long-term best option, this is a potential problem. That is why for such schemes additional measures may be considered such as: technology banding (4.6), sub-targets or carve-outs (4.8), or bonus/malus (4.7) measures. If implemented, the issue which technologies require what special attention in the quota design is obviously to be left with the political decision making processes.

[2] This typically applies as long as no significant changes will take place in natural gas, electricity and/or CO_2 prices. Excessive prices shifts (such as seen during 2021) may change this perspective, especially if the price hikes turn out to be long-lasting.

6. Summary and conclusions

Both the EU and some governments of EU Member States recently formulated proposals to green the gas system with the help of mandatory blending schemes, i.e. mixing natural gas with greener gases such as biobased gases and/or clean hydrogen (independently if the different types of gases are mixed within the same pipes, and/or mixed by allocating specific parts of the gas grid for specific types of gases). The underlying idea is to stepwise turn the natural gas system into a green gas system. In most of the proposals certificate trading is part of the suggested blending strategy recognising that any certificate-based blending can only be realized on the basis of physical introduction of the renewable gases.

Currently blending is applied in various markets but in gas markets it only exists by admixing biobased gas on a voluntary basis. That is why the concept to blend clean hydrogen into the natural gas mix on a mandatory basis is lacking any real life experiences, and therefore will have to be developed. This paper assesses how such a regime could be introduced such that it really works well from an economic and societal perspective by screening the existing literature on critical points regarding similar blending practices in other energy markets. In doing so a particular issue turned out to be how to deal with the policy dilemma's that characterised all options to try to deal with quota scheme 'weak spots'.

We found three issues to be the dominant concerns that need to be carefully considered in the design of any mandatory blending scheme.

A first key issue relates to the certificate market that is a crucial component of almost all suggested blending schemes. It seems crucial to make sure that the certificates are accepted to be completely reliable and environmentally sound right from the beginning, i.e. the blending scheme introductory phases. Also the certificate trading process needs to be transparent as possible from the beginning which means that transparency is key even in the introductory trading stage that likely is dominated by bilateral or 'over the counter' trading, long-term contracts, and a limited number of market parties. An example how the market transparency can be increased without providing sensible information of individual trades, is periodically publishing total traded volumes and average certificate prices, for example by brokers or exchange platforms.

The main dilemma's one is facing is to get trading and market development off the ground if trading margins are very thin while trading volumes are still small. In such conditions public support may needed to set up professional trading platforms and bear related costs before the market spontaneously develops towards maturity, because private traders enter the scene. Another dilemma relates to traded products. Investors may prefer long-term contracts to mitigate their risks, which may be required in the beginning but a market consisting of long-term bilateral contracts is one where existing, powerful players will dominate and no new entrants see a chance to enter. In other words, it is in conflict with the wish to create market liquidity and transparency so that also in this regard one has to find the proper balance as the market matures. A final dilemma may be to create a first class certificate reputation right from the start. This requires watertight processes of validation and verification based on authorised and advanced schemes that are accepted throughout the trading area. Having all this in place, however, may be time consuming and costly such that it unduly slows down the development of quota and start of quota pilots. The same applies for getting international consensus on quota design and certificate specifications: getting there may take very long but seems at the same time indispensable for opening up international certificate trading.

A second key issue relates to the risk of heavy certificate price volatility. This may be a serious risk not only in the early stages of certificate trading where volumes are still small and relatively large volume shifts in supply and demand may occur easily causing strong certificate price movement, but also in the mature stages as experiences in various emission trading schemes have shown. The reason is that mandatory blending quota essentially are based on volume driven policies leaving price formation to the market in which elasticities both of demand and supply are often low and regulatory risk high. Certificate price volatility therefore may typically be a systematic characteristic of mandatory blending quota schemes, which may frustrate the ultimate scheme target namely to incentivise investors to turn towards greener technologies. Their risk aversion may cause them to take a wait-and-see attitude.

That is why measures may be needed to try to restrict certificate price volatility, especially at the start, either by introducing minimum and maximum certificate prices, or by trying to steer price formation, or a combination of multiple measures. All options to do so, however, also have their backdrops. Guaranteeing minimum prices does require a fund and therefore lender at last resort to be able to purchase certificates against prices above market price levels; maximum prices may cause the quota to be surpassed and set a limit on the revenues that producers can make; and steering certificate prices via a flexible allocation regime increases regulatory risks which may paralyse investors. Yet a carefully balanced cocktail against undue volatility seems necessary. The measures can be stronger in the beginning and decline as the maturity and stability of the market evolves over time.

A third key issue relates to the degree of quota differentiation. This again may give rise to dilemma's. One perspective is to start from technology neutrality based on the notion that the market, not the policymaker should determine which production technologies are chosen to achieve the ultimate target, which is emission reduction. Another perspective, however, could be that one wants to prevent a lock in of an assumed ultimately most cost-effective technology by introducing a quota differentiation giving some priority to a currently less cost-effective but expected future more cost-effective technology. This perspective can even go a step further by, besides economic, distinguishing even more categories of technologies based on other reasons, or if it is perceived important that the future portfolio requires a mix of different technologies. There are multiple measures described to apply quota differentiation, including their advantages and disadvantages. The dilemma clearly is that the support for future cost-effectiveness of technologies is inherently uncertain and that at short notice less cost-effective technologies are prioritised via quota on the one hand, but that risks of lock-ins are prevented.

The paper has clarified all the above dilemma's based on experiences from real-life quota schemes and indicated the pro's and cons of the various choices. The advice of this report is to take into account the three issues described above very carefully, if mandatory blending of hydrogen is implemented. How the dilemma's will be solved ultimately, by weighting the advantages and drawbacks, will require political decision making.

References

[1] European Commission, “Proposal for an amending Directive (EU) 2018/2001,” European Commission, Brussels, 2021.

[2] European Commission, “Proposal for a regulation of the European Parliament and the Council on ensuring a level of playing field for sustainable air transport,” European Commission, Brussels, 2021.

[3] R. v. Zoelen, J. Bonetto and C. Jepma, “D8.1 Admixing Literature review,” HyDelta, 2021`.

[4] R. v. Zoelen, J. Bonetto and C. Jepma, “D8.2 Assessment Admixing Schemes,” HyDelta, 2021.

[5] R. v. Zoelen, J. Bonetto and C. Jepma, “D8.3 Pilots for introducing hydrogen blending quota,” HyDelta, 2022.

[6] P. Menanteau, D. Finon and M. Lamy, “Prices versus quantities: choosing policies for promoting the development of renewable energy,” *Energy Policy,* no. 31, pp. 799-812, 2003.

[7] A. Held, R. Haas and M. Ragwitz, “On the success of policy strategies for the promotion of renewable electricity from renewable energy sources in the EU,” *Energy & Environment,* vol. 17, no. 6, pp. 849-868, 2006.

[8] R. Haas, G. Resch, C. Panzer, S. Busch, M. Ragwitz and A. Held, “Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources - Lessons from EU countries,” *Energy,* no. 36, pp. 2186-2193, 2011.

[9] G. Bahr, D. Narita and W. Rickels, “Recent Developments in European Support Systems for Renewable Power,” *Kiel Policy Brief,* no. 53, 2012.

[10] Ecofys, “Design features of support schemes,” Ecofys, 2014.

[11] M. Aalto, “Call for economic sustainability - European renewable energy support schemes and the market,” Aalto University, Helsinki, 2014.

[12] PWEA, “Oversupply of green certificates,” 2017.

[13] Sandbag, “Drifting Towards Disaster? The ETS adrift in Europe´s climate efforts. Sandbag’s 5th annual report on the Environmental Outlook for the EU ETS,” 2013.

[14] G. Bel and S. Joseph, “Certificate Oversupply in the European Union Emission Trading System and its Impact on Technological Change,” IREA, 2015.

[15] M. Hustveit, J. S. Frogner and S.-E. Fleten, “Tradable green certificates for renewable support: The role of expectations and uncertainty,” *Energy,* vol. 141, pp. 1717-1727, December 2017.

[16] G. Wood and S. Dow, “What lessons have been learned in reforming the Renewables Obligation? An analysis of internal and external failures in UK renewable energy policy,” *Energy Policy,* no. 39, pp. 2228-2244, 2011.

[17] A. Verbruggen, “Performance evaluation of renewable energy support policies, applied on Flanders' tradable certification system,” *Energy Policy,* no. 37, pp. 1385-1394, 2009.

[18] A. Johnston, A. Kavali and K. NeuHoff, “Take-or-pay contracts for renewables deployment,” *Energy Policy,* no. 36, pp. 2481-2503, 2008.

[19] J. Lemming, “Financial risks for green electricity investors and producers in a tradable green certificate market,” *Energy Policy,* no. 31, pp. 21-32, 2003.

[20] H. Raadal, E. Dotzauer, O. Hanssen and H. Kildal, “The interaction between Electricity Disclosure and Tradable Green Certificates,” *Energy Policy,* no. 42, pp. 419-428, 2012.

[21] D. Toke, “The EU Renewable Directive - What is the fuss about trading,” *Energy Policy,* no. 38, pp. 3001-3008, 2008.

[22] F. Frei, A. Loder and C. Bening, “Liquidity in green power markets - An international overview,” *Renewable and sustainable energy reviews,* no. 93, pp. 674-690, 2018.

[23] F. Frei, A. Loder and C. R. Bening, “Liquidity in green power markets - An International review,” *Renewable and Sustainable Energy Reviews,* vol. 93, no. C, pp. 674-690, 2018.

[24] European Commission, “Directive of the European Parliament and of the Council on common rules for the internal markets in renewable and natural gases and in hydrogen,” European Commission, Brussels, 2021.

[25] Gas for Climate, “Market state and trends in renewable and low-carbon gases in Europe,” Gas for Climate, Utrecht, 2020.

[26] Gas for Climate, “Setting a binding target for 11% renewable gas,” Guidehouse, Utrecht, 2021.

[27] A. Johnston, K. Neuhoff, D. Fouquet, M. Ragwitz and G. Resch, “The proposed new EU renewables directive: interpretation, problems and prospects,” *European Energy and Environmental Law Review,* vol. 17, no. 3, pp. 126-145, 2008.

[28] IRENA, “Hydrogen: A renewable energy perspective,” IRENA, 2019.

[29] A. Piebalgs and C. Jones, “A Proposal for a Regulatory Framework for Hydrogen Guarantees of Origin,” Florence School of Regulation, 2020.

[30] A. Johnston, A. Kavali and K. Neuhoff, “Take-or-pay contracts for renewables deployment,” *Energy Policy,* no. 36, pp. 2481-2503, 2008.

[31] P. d. Río, “Analysing the interactions between renewable energy promotion and energy efficiency support schemes: The impact of different instruments and design elements,” *Energy Policy,* no. 38, pp. 4978-4989, 2010.

[32] S. Nagl, “The effect of weather uncertainty on the financial risk of green electricity producers under various renewable policies,” *Econstor,* 2013.

[33] E. Amundsen, F. Baldursson and J. Mortensen, “Price volatility and banking in green certificate markets,” *Environmental & Resource Economics,* no. 35, pp. 259-287, 2006.

[34] M. Verhagen, “Stimulering duurzame energieproductie,” Dutch Government, The Hague, 2012.

[35] Y. Wang, “Renewable electricity in Sweden: an analysis of policy and regulations,” *Energy Policy,* no. 34, pp. 1209-1220, 2006.

[36] R. Coenraads, G. Reece, C. Klessmann, M. Ragwitz, A. Held, G. Resch, C. Panzer, I. Konstantinaviciute and T. Chadim, “Renewable Energy Profiles: Final Version February 2008,” PROGRESS project, Utrecht, the Netherlands, 2008.

[37] G. Buckman, “The effectiveness of Renewable Portfolio Standard banding and carve-outs in supporting high-cost types of renewable electricity,” *Energy Policy,* no. 39, pp. 4105-4114, 2011.

[38] CertifHy, “Certification schemes: GO labels,” CertifHy, 2021. [Online]. Available: https://www.certifhy.eu/go-labels/. [Accessed 04 01 2022].

[39] C. Leguit, K. Kruit, F. Rooijers and H. Warmenhoven, “Contouren en instrumenten voor een Routekaart Groengas 2020-2050,” CE Delft, Delft, 2018.

[40] European Comission, “A European Green Deal,” 2019. [Online]. Available: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#highlights.

[41] H. Scharfa, F. Arnold and D. Lencz, “Future natural gas consumption in the context of decarbonization - A meta-analysis of scenarios modeling the German energy system,” *Energy Strategy Reviews,* vol. 33, 2021.

[42] European Comission, “A hydrogen strategy for a climate-neutral Europe,” 08 July 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0301&from=EN.

[43] European Comission, “Hydrogen factsheet - THE ROLE OF HYDROGEN IN MEETING OUR 2030 CLIMATE AND ENERGY TARGETS,” 2021.

[44] D. Schlund and M. Schönfisch, “Analysing the Impact of a Renewable Hydrogen Quota on the European Electricity and Natural Gas Markets,” Institute of Energy Economics at the University of Cologne (EWI), Cologne, 2021.

[45] IEEE, “IEEE Citation Guidelines,” [Online]. Available: https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf. [Accessed 19 03 2021].

[46] FCH2 JU, “Hydrogen Roadmap Europe,” 2019.

[47] FME, Ekinetix, Stratelligence, “Waterstof: kansen voor de Nederlandse industrie,” 2019.

[48] Ministry of Economic Affairs and Climate Policy, “Government Strategy on Hydrogen,” 06 04 2020. [Online]. Available: https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen.

[49] Voortgangsoverleg Klimaatakkoord, “National Climate Agreement - The Netherlands,” The Hague, 2019.

[50] Essent, “Opbouw gasprijs,” [Online]. Available: https://www.essent.nl/kennisbank/stroom-en-gas/energierekening/opbouw-gasprijs. [Accessed 6 8 2021].

[51] TNO, “Hydrogen for a sustainable energy supply,” TNO, [Online]. Available: https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-co2-neutral-industry/hydrogen-for-a-sustainable-energy-supply/new-research-centre-for-hydrogen-production/.

[52] D. Yeşilgöz-Zegerius, “Beantwoording motie ontwikkeling kader demonstratieprojecten,” Dutch Government, Den Hague, 2021.

[53] Nationaal Waterstofprogramma, “Waterstof in de Gebouwde Omgeving (WIGO),” Nationaal Waterstofprogramma, 2021.

[54] E. Wiebes, “Voortgang beleidsagenda kabinetsvisie waterstof,” Dutch Government, Den Hague, 2020.

[55] Authoriteit Consument & Markt, “Signaal 2021,” ACM, 2021.

[56] Minister van Economische, *Regeling gaskwaliteit,* 2014.

[57] Kiwa, “De impact van het bijmengen van waterstof op het gasdistributienet en de gebruiksapparatuur,” 2020.

[58] G. Maisonnier, J. Perrin, R. Steinberger-Wilckens, and S. C. Trümper, ““European Hydrogen Infrastructure Atlas” and “Industrial Excess Hydrogen Analysis” PART II: Industrial surplus hydrogen and markets and production,” Roads2HyCom, 2007.

[59] DNV-GL, “Filling the data gap: an update of the 2019 hydrogen supply in the Netherlands,” 26 November 2019. [Online]. Available: https://www.dnv.nl/news/filling-the-data-gap-an-update-of-the-2019-hydrogen-supply-in-the-netherlands-162721.

[60] TNO, “The Dutch hydrogen balance, and the current and future representation of hydrogen in the energy statistics,” Amsterdam, 2020.

[61] Netbeheer Nederland, “Waterstof,” Netbeheer Nederland, [Online]. Available: https://www.netbeheernederland.nl/dossiers/waterstof-56. [Accessed 8 9 2021].

[62] M. Ragwitz, P. d. Río González and G. Resch, “Assessing the advantages and drawbacks of government trading guarantees of origin for renewable electricity in Europe,” *Energy Policy,* no. 37, pp. 300-307, 2009.

[63] M. Tanaka, “Market power in renewable portfolio standards,” *Energy Economics,* no. 39, pp. 187-196, 2013.

[64] N. v. d. Linden, M. Uyterlinde, C. Vrolijk, L. Nilsson, J. Khan, K. Astrand, K. Ericsson and R. Wiser, "Review of international experience with renewable energy obligation support mechanisms," ECN, 2005.

[65] C. d. Jong, "Renewable energy certificates," *The financials of renewable power and PPA contracts,* October 2020.

[66] O. Tlili, C. Mansilla, D. Frimat and Y. Perez, "Hydrogen market penetration feasibility assessment: Mobility and natural gas markets in the US, Europe, China and Japan," *International Journal of Hydrogen Energy,* vol. 44, no. 31, pp. 16048-16068, 2019.