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SUPPORT MECHANISMS FOR LOW-CARBON HYDROGEN: THE RISKS OF SEGMENTING A COMMODITY MARKET

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Abstract

Although the actual scope of the hydrogen sector is subject to great uncertainty, a global wave of support mechanisms for low-carbon hydrogen is being registered. In many cases, these schemes aim to bridge the gap between the current cost of producing clean hydrogen and the price that existing and potential end users are willing to pay for it. In doing so, they tend to introduce a regulatory segmentation into the hydrogen market, preventing supported hydrogen from being supplied to certain end uses, or providing support to production/end use pairs. This approach would require a burdensome monitoring, which is prone to fraud, and could lead to inefficient outcomes from a system-wide perspective. In contrast to these approaches, we argue for centralised hydrogen support mechanisms that bring together producers and end users in the same bidding process. This approach, whose high-level design is discussed in the article, would allow the most competitive production projects to be selected and this initial low-carbon hydrogen generation to be secured by those end uses that are willing to pay the highest price for it and could therefore be more efficiently decarbonised with hydrogen.

Keywords

Hydrogen; Decarbonisation; Support mechanism; Auction; Market design; Risk-hedging.

1 INTRODUCTION

Low-carbon hydrogen plays a major role in almost all decarbonisation pathways envisaged in the last decade [1][2][3]. Beyond its role as a sustainable feedstock for the chemical industry, low-carbon hydrogen is expected to become a key energy carrier in the future, enabling the decarbonisation of many end uses that cannot be electrified and providing much needed flexibility to a renewables-dominated power sector. However, there are large uncertainties about the actual scope of hydrogen as an energy vector. In the most optimistic scenarios [2][4], low-carbon hydrogen reaches almost all end uses, including transport (road, maritime, and aviation), industry (high-temperature heat) and buildings (space heating), and becomes a relevant input to the power sector, through direct combustion or fuel cells. In the most pessimistic scenarios [5][6], which highlight the technical and economic challenges of the hydrogen industry, low-carbon hydrogen plays a relevant role in decarbonising part of the industrial demand, but only covers some niches in the transport sector, while its use in the power sector is limited to a kind of strategic reserve to cover seasonal or multi-year fluctuations in renewable electricity generation. The rest of the energy demand would be met by massive electrification and biofuels.

Hydrogen hype[1] has risen and fallen many times in recent decades [7][8][9][10], but this time there is a disruptive element, namely strong political commitment. Urged by climate change, many policymakers are acting to build a hydrogen economy, despite the uncertainties mentioned above. A first wave of national and regional hydrogen roadmaps and strategies have been published since 2020 and many memorandums of understanding for international trade have been signed [13]. A second wave of policies is now emerging, in the form of support mechanisms for different elements of the hydrogen supply chain, and billions of public funds will soon be flowing into this new energy sector. Support mechanisms for low-carbon hydrogen production have been introduced or are being developed in the United States, the European Union, Great Britain, Australia, Canada, Japan, India, South Korea, Egypt, Germany, Denmark, the Netherlands, Portugal, Spain, Italy, Sweden, Poland, Romania and Lithuania[2]. The design of these mechanisms varies widely, but they are rapidly transitioning from programmes that fund demonstration projects based on multi-criteria evaluation to price-based auctions meant to drive a large-scale deployment of hydrogen production facilities.

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[1] This article is agnostic on the scope of the hydrogen sector and does not argue in favour of the introduction of low-carbon hydrogen support schemes. We have no data to contribute to this discussion. However, as economic aid is already being granted in many jurisdictions, we would like to draw the attention of academics and regulators to the efficient design of these support mechanisms.

[2] For a detailed taxonomy of these hydrogen support mechanisms, the reader is referred to [11]. For an evaluation of different designs, the reader is referred to [12].

Unlike other energy technologies, low-carbon hydrogen production is characterised by a low proportion of capital expenditure in the cost structure [14][15]. Most of the risk faced by hydrogen producers is related to operating cash flow, i.e., to the price of the energy source and to the price and volume of hydrogen sales. Therefore, many of the support schemes mentioned above are based on risk-hedging instruments, such as long-term contracts for a fixed price or a fixed or variable premium on hydrogen production [12]. Long-term contracts based on a fixed price are provided in support schemes such as the Portuguese hydrogen auction [18] or the German H2Global scheme [19] (which targets hydrogen imports). Examples of support schemes based on fixed premia are the European Commission's Innovation Fund auction [20] or the Danish auction for Power-to-X projects [21]. Variable premia can be found in the British Low Carbon Hydrogen Agreements (LCHAs) [22], the Australian Hydrogen Headstart funding [23], and the Dutch hydrogen auction [24]. This form of support is likely to become prevalent in the future. However, designing these aid mechanisms and risk-hedging tools for a nascent sector with almost no infrastructure in place and no reference market for low-carbon hydrogen is, at the very least, extremely complex.

In the aftermath of the Covid-19 pandemic, the International Energy Agency [25] emphasised that the hydrogen industry was at the technology development stage where wind and solar had been two decades earlier, and urged governments to take advantage of the expertise gained from supporting renewable energy sources to target economic aid to low-carbon hydrogen in the most efficient way. After a thorough analysis of more than fifteen hydrogen support schemes implemented in different regions of the world, we would like to share some initial thoughts on the risk that these mechanisms artificially segment the hydrogen market into production/end use pairs. We argue that, as soon as infrastructure development allows (or even sooner), hydrogen support schemes should move towards market-wide mechanisms where supply and demand can meet on the basis of economic efficiency, as in other commodity markets. Our aim is to stimulate academic discussion on a topic that is still extremely underrepresented in the literature (hydrogen support schemes) [26] and to provide a theoretical framework for policymakers responsible for designing the next generation of support schemes.

2 THE NEED FOR AID AND THE RISKS OF SEGMENTATION

The need to provide hydrogen with economic aid arises from the current gap between the cost of hydrogen production (expressed as the Levelised Cost of Hydrogen, or LCOH) and the price that existing and potential consumers may be willing to pay for low-carbon hydrogen. Production costs have been extensively studied and forecasts are available for most production pathways [13]. The LCOH depends on the production technology (electrolysis, steam methane reforming, hydrogen from biomass) and the price of the energy source, which could also create a price difference between domestic and imported hydrogen. End-user willingness to pay is less explored in the literature and depends on several factors. It certainly depends on the energy source that the end use currently relies on and its price. In addition, some end uses may be subject to some form of carbon pricing (such as the EU ETS), while others may be exempted or excluded from such schemes. Some end uses may be able to switch to low-carbon hydrogen immediately without changing their industrial process (as demand for hydrogen as a feedstock), while others may require large capital expenditures to make the switch.

This wide range of different alternatives on both the supply and demand side of the future hydrogen market means that the economic gap to be covered by a support mechanism will depend on the LCOH of the production project and the willingness to pay of the end use to be decarbonised. This line of reasoning may lead to the creation of segmented hydrogen support schemes that provide targeted economic aid to each production/end use pair, as in chart 1 of Figure 1. A similar result is achieved if the support scheme targets production projects but requires them to identify the off-taker for the hydrogen they will produce and, for example, defines the economic aid according to the sales price of the contract. This approach encourages project developers to enter into contracts with off-takers, creating similar production/end use pairs, albeit in an indirect way, as shown in chart 2 of Figure 1. End uses could also receive specific support (e.g., grants for investments that enable fuel switching or Carbon Contracts for Difference - CCfDs), which may influence the sales price they are willing to accept. Examples of support schemes based on this philosophy are the British LCHAs, the Australian Hydrogen Headstart or the European Innovation Fund auction.

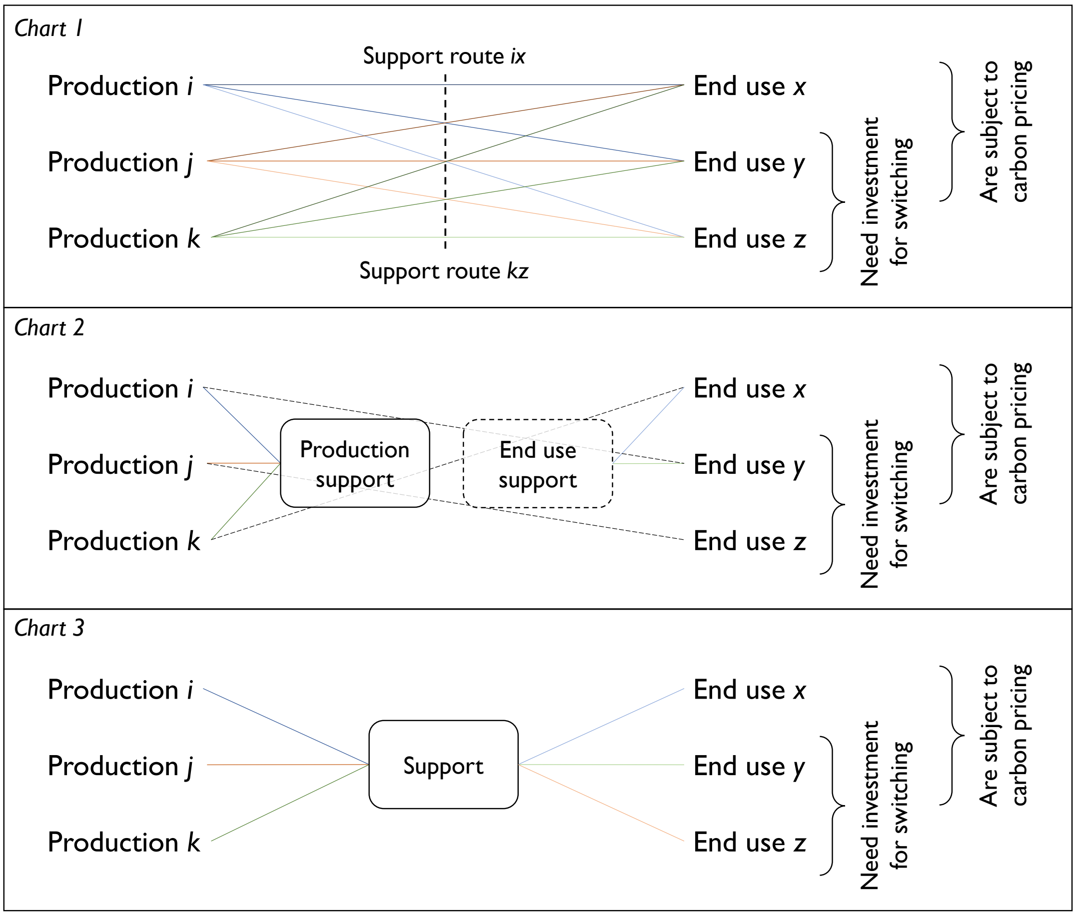

Figure 1. Different approaches to address with the risk of segmentation of the hydrogen market

An alternative design that does not require the direct or indirect creation of production/end use pairs is to implement a centralised support mechanism that brings together producers and end users. This may require an entity acting as a central buyer of low-carbon hydrogen. Schemes based on this concept are the German H2Global, where Hintco, a subsidiary of the H2Global Foundation, acts as the central buyer, and the Portuguese hydrogen auctions, where Galp, the national champion in the oil & gas sector, procures all supported hydrogen as a "last-resort trader" [18]. However, the H2Global scheme focuses on hydrogen imports and the scheme is segmented between different hydrogen derivatives, hampering the centralised approach, while the Portuguese support mechanism only considers a single "intermediate" end use, i.e., blending, and the hydrogen is then sold at the price of natural gas. The following section analyses how a centralised hydrogen support mechanism that avoids segmentation could be designed.

3 A BLUEPRINT FOR LOW-CARBON HYDROGEN SUPPORT SCHEMES AND MARKET CREATION

If a low-carbon hydrogen marketplace existed today, it would look similar to the price-quantity graph in Figure 2. The supply and demand curves do not intersect, which is why support is needed. Some end users may also have a negative willingness to pay for low-carbon hydrogen if the capital expenditure required for switching is sufficiently high. Furthermore, depending on how hydrogen or its derivatives are transported and distributed, some of these supply and demand bids (in fact most of them, at an early stage) may not be matched due to a lack of infrastructure connecting them. These constraints will physically segment the emerging hydrogen market.

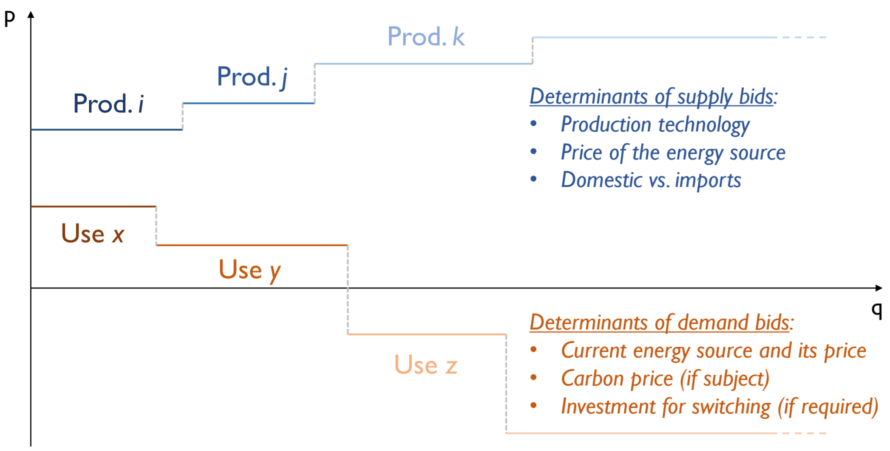

Figure 2. A potential low-carbon hydrogen marketplace

However, current support mechanisms introduce a regulatory segmentation of the low-carbon hydrogen market that goes beyond this physical segmentation. Some end uses may be explicitly excluded from the support mechanism. For example, in Great Britain supported hydrogen cannot be used as a feedstock, nor in the transport sector if it also receives aid under the RTFO (Renewable Transport Fuel Obligation) scheme [22]. In Portugal, as mentioned above, the only permitted end use for support hydrogen is blending into the gas network. In Italy, supported hydrogen cannot be used to generate electricity [27]. These restrictions are often justified by the need to promote the penetration of hydrogen in certain economic sectors or to encourage its role as an energy vector. In other cases, they result from the application of aid cumulation rules, which prohibit low-carbon hydrogen to be supported twice.

Nonetheless, several experts [13] highlighted the advantages of securing the initial development of the low-carbon hydrogen sector through those end uses that already exist (and currently rely on fossil-based hydrogen) and represent low-hanging fruit for the industry. In addition, there is no theoretical reason to prohibit aid cumulation (i.e., the provision of aid to different elements of the supply chain through separate policies) as such. It is important to ensure a high degree of coordination between different hydrogen support policies, but they can operate in parallel as long as they do not result in overcompensation for project developers[3].

A further segmentation of the hydrogen market occurs, as mentioned above, when support is directly or indirectly provided to production/end use pairs, by requiring project developers to back their bid with an off-taker contract. Although it is important to ensure that low-carbon hydrogen production is backed by a real demand that justifies the support, the outcome of this bilateral pairing of production projects and end uses may not be the most efficient from a system-wide perspective.

All these approaches have another very evident drawback: they require a complex and cumbersome monitoring. If the support is pair-specific, a body will have to monitor that all these hydrogen routes are respected by market agents, or that supported hydrogen is not delivered to end uses that have been restricted. This situation is not new to the energy sector and past experience, for example with rebated liquid fuels for the agricultural sector, suggests that it is prone to fraud [16][17].

3.1 A centralised support mechanism for low-carbon hydrogen

Some of these issues and complexities may be addressed by a centralised support scheme that brings together producers and end users in the same bidding process. All parties would bid a volume of low-carbon hydrogen they are willing to consume/produce during the time horizon of the support scheme and the price they are willing to pay/be paid for it. Supply and demand bids would be selected according to the support scheme budget. If the auction were cleared pay-as-bid, the result would be similar to that shown in chart 1 of Figure 3. The support would therefore take the form of a fixed price[4] for the hydrogen consumed or

[3] For example, a particular end use may receive a grant for the capital expenditure required to switch to low-carbon hydrogen, which will increase its willingness to pay for that hydrogen. If producers receive a production premium that internalises the off-taker's willingness to pay, there is no double compensation.

[4] When a liquid and efficient low-carbon hydrogen market emerges, this fixed price could be transformed into the strike price of a variable premium, and the support mechanism could be refined to encourage an efficient

produced, with the mechanism covering the gap between supply and demand bids through its budget. Depending on the risk-allocation strategy, both supply and demand bids could be indexed to the relevant underlying variables (see Figure 2). A pay-as-cleared approach is also possible, as shown in chart 2 of Figure 3. Since the supply and demand curves do not currently intersect, a marginal clearing would result in two prices, one marginal price for supply and one for demand. The pros and cons of these two clearing approaches have been extensively discussed in the academic literature [28][29]. Although marginal pricing could avoid gaming and strategic bidding by market agents, it should be noted that all price-based support mechanisms for hydrogen production introduced so far have been cleared using a pay-as-bid approach.

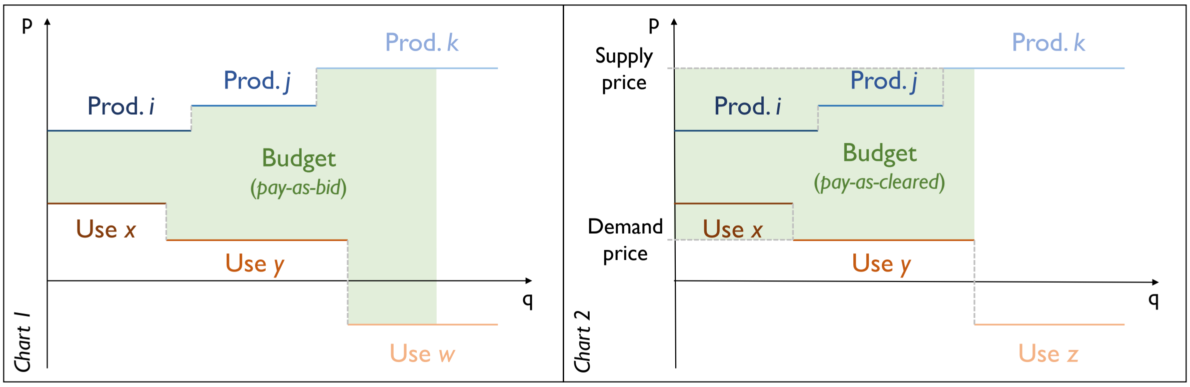

Figure 3. Centralised support mechanisms involving supply and demand with different clearing approaches (with available budget being the constraint for the clearing regardless of the approach)

A centralised support mechanism has many advantages over a support scheme that segments the hydrogen market. If decarbonisation policies are properly coordinated, a centralised approach allows the most competitive production projects to be selected and this initial low-carbon hydrogen generation to be secured by those end uses that are willing to pay the highest price for it and could therefore be more efficiently decarbonised through hydrogen[5]. Furthermore, a centralised approach also improves market transparency and,

operation of hydrogen production facilities (the discussion is similar to that around the design of CfDs for renewable power projects).

[5] Initially, this may result in low-carbon hydrogen production being concentrated in one or a few hydrogen end uses. However, this is not an inefficient outcome, if the main objective of hydrogen support is decarbonisation and emissions reduction. If the policy maker wants to incentivise the decarbonisation of a particular end use with hydrogen, specific demand-side measures can be introduced, such as grants for fuel switching investments or quota systems.

more importantly, price disclosure, which will be essential for scaling up the low-carbon hydrogen market. At the same time, it does not require the burdensome monitoring that would be required if support were segmented or if some end uses were excluded from the mechanism.

Another advantage of a centralised approach is that it could be more easily coordinated with the planning of the hydrogen infrastructure (transport, distribution, and storage) and the specific support mechanisms that may be introduced for its deployment. Support schemes for hydrogen production can be based on specific delivery points (such as the German H2Global [19]) or leave the development of specific small-scale infrastructure to project developers, who would internalise these costs in the support they require. However, while this approach may be appropriate in the very early stages of the hydrogen sector's development, it will soon have to be replaced by some form of centralised planning, at least for networks. A centralised support mechanism, such as the one proposed in this section, would allow to identify the best locations for hydrogen production and consumption, which could be used as an input for infrastructure planning. The tender itself could take infrastructure constraints into account as an input, leading to a zonal clearing of the auction, or it could be coordinated with infrastructure planning, in a unified process that could support the deployment of both hydrogen production/consumption and networks[6].

Finally, a centralised support mechanism can also facilitate the transition to a competitive low-carbon hydrogen market. Learning curves of hydrogen production technologies and other decarbonisation policies may rapidly improve the economic viability of hydrogen solutions. When the supply and demand curves of the support mechanism start to intersect, the auction could be split into two parts: a first part where supply and demand bids converge, which would act as a sort of competitive long-term market for hydrogen and be cleared at the marginal price, and a second part where supply and demand bids start to diverge, which would still be cleared according to the support mechanism rules mentioned above, subject to budget constraints, as shown in Figure 4.

[6] Many regulators are working on the design of specific support schemes for hydrogen infrastructure. Great Britain is designing a hydrogen transport business model based on the Regulatory Asset Base (RAB), typical of monopoly regulation, but with a further subsidy to avoid prohibitive charges for the first users of the hydrogen network [30].

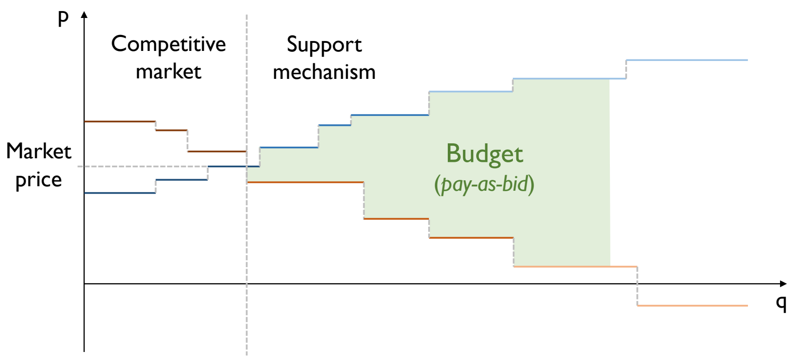

Figure 4. Transition from the support mechanism to a competitive long-term market

4 CONCULSIONS

Support mechanisms for low-carbon hydrogen are being introduced in all major economies by policymakers who believe that this energy vector will play a central role in the energy transition. Due to the cost structure of hydrogen projects, many of these schemes are based on risk-hedging instruments that close the gap between the current cost of producing low-carbon hydrogen and the price that existing and potential end users are willing to pay for it. As explained in this article, most of these schemes tend to introduce regulatory segmentation into the hydrogen market, by directly or indirectly providing support to production/end use pairs. We argue that this approach can lead to inefficient outcomes and requires complex monitoring that is prone to fraud. We advocate centralised hydrogen support mechanisms that bring together producers and end users in the same bidding process. This approach has several advantages in terms of efficiency of the bid selection, coordination with the hydrogen infrastructure planning process, transparency and price discovery, or transition to a competitive hydrogen market. We have focused our assessment and recommendation on the dichotomy between centralised and segmented support schemes. We are aware that we have not covered many relevant aspects of the design of hydrogen support schemes (volume risk, eligibility criteria, penalties, etc.), which can be addressed in future work.

Although the design of this first generation of hydrogen support mechanisms is inevitably constrained by the limitations of this nascent industry, especially in terms of infrastructure, we believe it is important to stimulate a discussion among experts and policymakers on how these schemes should evolve in the near future to guarantee value for the large amount of public money that will soon be flowing into this new energy sector.

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