Sustainable Energy Supply Transition: The Value of Hydrogen for Business Customers

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Abstract

Purpose: While some hydrogen (H_2) products are available in the industrial market, new clean H_2 applications are considered critical alternatives in decarbonization efforts. As suppliers need to understand how business customers conceive the value of hydrogen, this paper aims to investigate how the value of hydrogen is described in the published evidence and to identify or propose specific tools to assess its value.

Methodology: An integrative literature review is developed to synthesize studies on the value of hydrogen to identify the main value categories. Then, we create a novel guideline by linking three value dimensions: 1) the product-oriented value (including sustainability), 2) the elements of B2B value, and 3) the concept of goal-oriented value.

Findings: This paper categorizes the aspects of value discussed so far in the literature, suggesting conceptualizing the value of H_2 value-in-use based on economic, environmental, social, and technological categories. The missing value categories from the marketing perspective are related to perceived value. A comprehensive guideline for assessing the value of H_2 for business customers was developed to address that gap. The guideline can evaluate hydrogen from a multicategory perspective and compare new hydrogen products with alternatives.

Originality: First, we present the value of hydrogen in the B2B marketing discussion. Second, we propose four hydrogen value categories based on the current state-of-the-art. Third, we developed the multicategory guideline for assessing the value of hydrogen products for business customers (VH_2-BC).

Keywords: hydrogen, value, B2B marketing, multicategory decision-making, supply chain, supply network

1. Introduction

There is a need to accelerate the energy transition due to global climate change and high air pollution levels. Renewable energy sources (e.g., solar and wind) are considered one of the main alternatives in decarbonization roadmaps. Decreasing the share of fossil fuels in the energy mix and using more renewable sources gives high hopes for sustainable development by reducing CO_2 emissions in industry, transportation, and building sectors (IRENA Coalition for Action, 2021). Although the intermittency of renewables is one of their main drawbacks, it can be mitigated using energy storage systems. In this context, hydrogen (H_2) represents a promising alternative to increase the flexibility of renewable energy systems, as H_2 is an energy carrier capable of storing and transporting energy (Azzaro-Pantel, 2018). The actual reserves of natural hydrogen are unknown, and commercial volumes of hydrogen are currently produced mainly via steam methane reforming (Bendall, 2022). Today, H_2 is used as a feedstock in specific industrial sectors (e.g., refineries, ammonia production).

New sectors and applications are projected to use low-carbon H_2 for the energy transition. The H_2 cost is expected to play an essential role in its acceptability. The European Commission (2021) has announced an ambitious goal to bring the renewable hydrogen cost[1] below 1.8 €/kg by 2030 [~$2] and to increase Europe's annual production of green hydrogen to 10 million tones by 2030 (European Commission, 2020; FCH JU, 2021). McKinsey (2022) predicts a significant decrease in green hydrogen costs and increased demand for it in the next decade, so essential changes in that market are expected. Another report, commissioned by GrandViewResearch (2022), estimates the hydrogen generation market size at 130 billion in 2021 and expects it to expand by 6.4% annually to 2030. These examples clearly illustrate the growing importance of hydrogen in efforts around a sustainable energy transition. Realizing this new energy carrier's potential requires mobilizing political support, investment capital, public acceptance, and technology development. Such mobilization will be successful only if new hydrogen products are commercialized. For this purpose, stakeholders in the hydrogen supply chain, including customers, should understand the value of hydrogen from a business perspective. However, the understanding of that value faces some limitations. It is dominated by economic (costs) and environmental (low emissions) aspects, while the social pillar of sustainability might get less attention. Arguments promoting the use of "clean" hydrogen tend to use this perspective by quantifying the carbon footprint of hydrogen with an associated cost by assuming that the central element of the value of hydrogen is related to environmental sustainability. However, a value definition oriented to sustainability should include economic, environmental, and social benefits to customers and society, considering short and long-term effects (Laukkanen & Tura, 2020; Patala et al., 2016).

[1] Estimated production costs for fossil-based hydrogen were around 1.5 €/kg for the EU, highly dependent on natural gas prices, and disregarding the cost of CO_2, on the other hand, costs for fossil-based hydrogen with carbon capture and storage were around 2 €/kg, and renewable hydrogen costs ranged between 2.5-5.5 €/kg (European Commission, 2020). External sales price of green hydrogen varies depending on the energy source, technology type and country. Prices range between 2-16 €/kg (CHP, 2024; European Alternative Fuels Observatory, 2022; ICIS, 2023).

In this paper, we aim to 1) identify the most treated elements of the value of hydrogen in recent literature and 2) identify or propose specific tools that might be helpful for business customers to understand or assess the value of hydrogen for specific purposes. We first reviewed the B2B marketing literature, which involved intense value discussions and how it relates to sustainability issues. B2B marketing literature emphasizes differences between value propositions representing the supplier's perspective and the customer's perceived value (Zeithaml et al., 2020). It points out that as every company has a different capability to assess value and works differently in various market segments, they use their architecture of value on specific configurations of elements (Payne, 2017). However, the value of sustainable options is still explained to a minimal extent. That leads to the first research question:

(RQ1): How is the value of hydrogen described in the published evidence?

To answer this, we analyze the studies on the value of hydrogen through an integrative literature review. We identify and categorize several value categories available in the published evidence. However, these categories are related to the product but do not include the business customer's perspective. Following the calls for a better understanding of how customers conceive and measure the value of sustainable offers (Keränen & Liozu, 2020; Wengler et al., 2020), our second research question is:

(RQ2) How can business customers measure and compare the value of H_2 products vs other alternatives?

To answer it, we build on the concepts of perceived value and value-in-use, which emphasize long-term supplier goals (Kleinaltenkamp et al., 2022), and develop a tool for multicategory evaluation of the value of hydrogen for business customers.

This paper contributes to the literature on B2B marketing by suggesting that hydrogen can be presented as a sustainable energy carrier that can support the development of renewable sources and influence many economic sectors. This way, we answer Upham and colleagues' (2020) call to pay more attention to hydrogen value communication with business actors. We also reply to De-León Almaraz and colleagues' call for (1) the inclusion of sustainability considerations into hydrogen supply network deployment studies (2022) and intend to address the gap concerning the lack of a definition of the value of hydrogen (2023). This research extends the understanding of the value of hydrogen by taking a business customer perspective, pointing out its desires and goals related to economic, environmental, social, and technological aspects of value.

2. Conceptual background

2.1 Customer-oriented value

B2B literature has traditionally associated value for business customers with the difference between benefits and costs (Zeithaml, 1998). Then, researchers accepted that value for business customers is derived from product use (Eggert & Ulaga, 2002). Eggert and his team (2019) suggested a deeper understanding of such value in a sequence of expected, experienced, and relational value-in-use. The first defines the consequences that a customer expects from the supplier's offering. The second is determined by the economic aspects of implementing a supplier's offering (Deleon & Chatterjee, 2017). Relational value captures the long-term perspective of the customer's relationship with the supplier and the sum of benefits and losses in subsequent exchanges and collaborations (Latinovic & Chatterjee, 2022). Thus, suppliers provide complex offerings to business customers, and the value is not built by a specific product or service attribute. Still, it is created during usage (Bischoff et al., 2023).

Several authors emphasized the need to decompose value-in-use perceived by customers to link better architectures of value propositions (Bohnsack & Pinkse, 2017; Hinterhuber, 2017; Payne & Frow, 2014). Maglio & Spohrer (2008) suggested that value consists of bundles of products, services, support, service, and knowledge, adding value to the product. Fiol et al. (2011) identified functional, social, and emotional elements of value. Studying value structure for business customers has been summarized in the B2B value pyramid model (Almquist et al., 2018). This model is conceptually embedded in the hierarchy of needs and assumes that business buyers expect to fulfill their collective needs. These needs range from meeting basic requirements, gaining from economic improvements and higher performance, and improving ease of doing business. This model also highlights the value for individual decision-makers that derives from supporting the professional development of persons and inspiring them in organizations.

The mainstream literature suggests that a better understanding of value should be based on the architecture of value and analysis of its components. Still, Kleinaltenkampf et al. (2022) recently suggested developing a framework by linking value to goals that are crucial drivers of customer firms' decisions (Huber & Kleinaltenkamp, 2023). Based on the firm's behavioral theory and goal-directed behavior, they propose that goal achievement defines customer perception of value. Assuming that customers achieve operational and strategic goals by using particular goods, services, or solutions, Kleinaltenkampf et al. (2022) reaffirm the concept of Woodruff (1997), who suggested that the perceived value-in-use depends on the degree of experienced goal achievement. Organizations consist of individuals and groups with different roles and worldviews (Leszczyński et al., 2022), so actors can have their organizational and individual goals. Then, value-in-use is notionally linked to those goals. Collective and individual users' attitudes, emotions, and norms form their desires, which create the foundations for goals. Different actors will link the evaluation of varying energy alternatives concerning achieving their goals with implications in their perception of value for the evaluated option (Kleinaltenkamp et al., 2022).

Studies in B2B marketing tried to build a link between value-in-use and sustainability, mainly showing that environmental strategic focus relates to financial performance (Sharma & Iyer, 2012). However, suppliers of sustainable offers need to know how to communicate value-in-use to their customers, for whom it might be challenging to evaluate such offers' benefits (Ramirez et al., 2014). Therefore, researchers suggested using a broader framework by suppliers to communicate sustainable elements of value (Ranta et al., 2020), paying attention to the cooperation of different actors in business networks to generate sustainable value (Patala et al., 2016), and understanding the value-in-use in the long-term (Urbinati et al., 2017). These studies commonly indicate the challenge of quantification of sustainable elements of value. As economic benefits can be presented in monetary means, they are hardly comparable with environmental and social benefits, which can lead to a biased understanding of value (Knizkov

& Arlinghaus, 2019). Another feature of research on sustainable value-in-use is the focus on suppliers' propositions and the deficiency of understanding customer perception (Kristensen & Remmen, 2019). Sairanen et al. (2024) conclude that economic, functional, and relationship value aspects are usually studied in line with ethical, strategic, and systemic dimensions when the circular economy is in the context.

Recently, the discussion on sustainable value in B2B literature highlighted different facets of fuels and energy. Studies referred to strategies for fuel market development (Rawat & Garg, 2023), strategies for building environmental legitimacy of companies from the energy sector (Ellimäki et al., 2021), business-driven sustainable development fostering fossil-free fuel consumption (Svensson & Padin, 2021), mechanisms used to generate offerings that reduce CO_2 and increase economic value (Haftor & Climent, 2021), supply uncertainty of bioenergy from organic residues (Knight et al., 2015), cooperation in networks in the wind energy industry (Zhang & Cheng Guan, 2019), increase of energy efficiency of vehicles and its benefits for corporate brand image (Rubio et al., 2020), and efficiency of energy sustainable practices versus circularity in manufacturing companies (Nishant et al., 2016). However, there is a risk of greenwashing when the organizations' actual efforts on sustainability are lower than the marketing campaigns around them. The problem of greenwashing practices based on energy sources has been raised in Kapitan et al. (2019). The abovementioned studies discussed fossil and renewable fuels (e.g., petrol, wind, natural gas) but not hydrogen. In this sense, we ask how the published evidence describes the hydrogen value.

2.2. Hydrogen products, supply chain, and colors

This section briefly explains the context of hydrogen products and their supply chains. Several products can be associated with the hydrogen economy. A hydrogen product can be defined as an item related to hydrogen that is subject to be produced, bought, used, disposed of, and, in some cases, reused or recycled. Hydrogen products have a lifecycle. Based on its final use, we can distinguish three main types of H_2 products (Figure 1a): a) H_2 feedstock, b) H_2 fuel, and c) H_2 technologies.

As a feedstock, hydrogen has been used in industry for several decades (e.g., refinery, chemical, ammonia industries, etc.). In the following years, business customers are expected to look for low-carbon hydrogen options. As a fuel, hydrogen is expected to play an important role in mobility by being used in fuel cell electric vehicles or internal combustion engines (heavy-duty cars, rails, maritime, and aviation). As H_2 technologies, products such as fuel cells, electrolyzers, fuel cell electric vehicles (e.g., hydrogen buses), refueling stations, and hydrogen tanks, among many others, are needed to produce or use hydrogen fuel or feedstock.

A B2B customer might need to evaluate one or several H_2 products. For example, a logistics company might assess the value of H_2 buses by considering the availability of hydrogen refueling stations on commonly used roads, the price of hydrogen fuel, and the total cost of ownership of fuel cell electric buses (De-León Almaraz et al., 2023).

There are several alternatives to produce and distribute H_2 to the customer. The associated supply chain affects the economic and environmental value of hydrogen. Although hydrogen is the most abundant element on Earth, it is rarely available in its pure form (natural or white hydrogen). In most cases, hydrogen needs the link among several processes in a supply chain to be produced, conditioned, stored, transported, and distributed. To illustrate the hydrogen supply chain (HSC),[2] we present Figure 1b. The stakeholders for the most basic representation of the HSC are agents in the following nodes (Chen et al., 2021; De-León Almaraz et al., 2013; Jarvis & Samsatli, 2018): energy sources (solar (PV), wind, hydro, geothermal, nuclear, biomass, methane, coal, etc.), production technology (water electrolysis, steam methane reforming, gasification, pyrolysis, etc.), hydrogen conditioning form (gas, liquid or solid), transportation (tube trailers and pipeline for gaseous H_2; tanker trucks for liquid H_2; solid-state hydrides for solid H_2), storage (cylindrical tanks for gaseous H_2, spherical tanks for liquid H_2, solid-state hydrides for solid H_2), and distribution to industry or other markets like refueling stations.

The focal actor in the HSC can be the final customer (e.g., hydrogen vehicle user who needs hydrogen fuel) or a business customer (e.g., logistics companies (Coleman et al., 2020), industrial manufacturers (Parra et al., 2019), or energy hubs (Quarton & Samsatli, 2021)).

As displayed in Figures 1 b and c, based on the different paths followed in the HSC, other types (colors) of hydrogen fuel or feedstock can be produced by transferring differences in costs and related emissions (Ajanovic et al., 2022; Bruninx et al., 2022; Feder, 2021; Ikonnikova et al., 2023). However, the debate about hydrogen labeling has led to new definitions like those proposed by the European Commission, where renewable fuels can be labeled according to the Renewable Fuels of Non-Biological Origin (RFNBO) criteria derived from the Renewable Energy Directive (RED II, 2018/2001). In the future, it might be expected to categorize hydrogen fuel and feedstock based on the carbon footprint instead of by colors, and different pricing can be associated with low- or high-carbon hydrogen. This could represent an advantage for countries with low amounts of renewable energy sources but low emissions in their grid. It is also beneficial for operations with intentions to produce blue hydrogen (gray hydrogen with carbon capture and storage).

As previously introduced, the approach used to measure the value of hydrogen by considering the hydrogen supply chain is dominated by quantification, primarily for economic and environmental aspects. In the public discourse, it is promoted that green hydrogen would be the option that gives more value to the final consumer. However, it has been reported in several works from the last two decades that the cost of green hydrogen is still prohibited due to the lack of infrastructure, while a hydrogen low-cost option has a negative environmental impact (Almansoori & Shah, 2006; De-León Almaraz et al., 2022; Guillén-Gosálbez et al., 2010; Talebian et al., 2021). Moreover, some social and pragmatic aspects of hydrogen usage can also affect the systems' value.

As previously introduced, this work is interested in identifying the value of hydrogen for business customers. Now that the main concepts around customer-oriented value and hydrogen

[2] In several energy systems (hydrogen included), the following terms are used as synonyms: supply network, supply chain, and value chain (Coleman et al., 2020; Quarton & Samsatli, 2021; Samsatli & Samsatli, 2018, 2019; Zhao et al., 2022)

products have been introduced, it is possible to explore systematically the current state of the art of hydrogen's value.

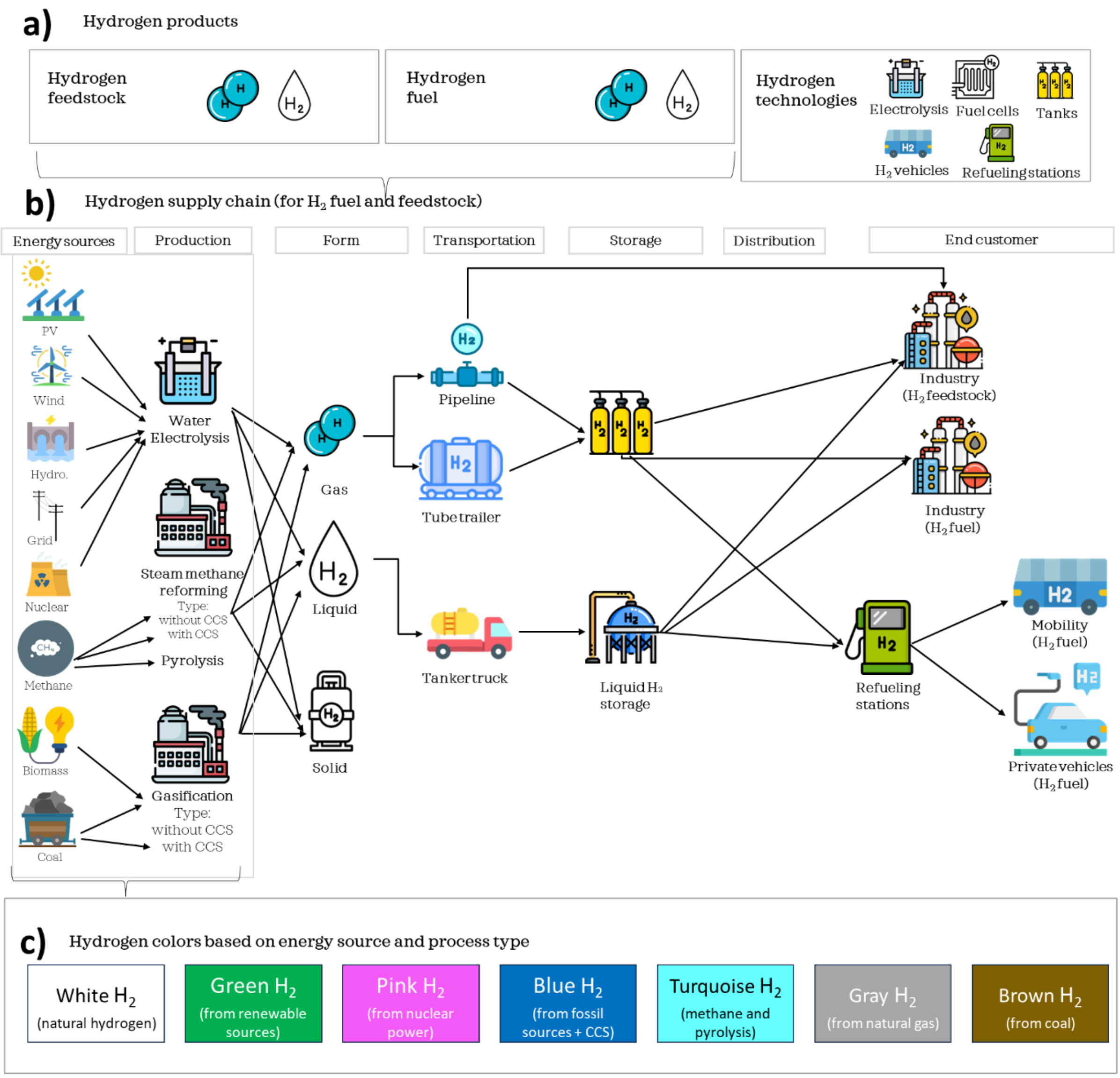

Figure 1. Hydrogen Products, Supply Chain, and Colors

(Source: Authors own work with icons from https://www.flaticon.com/)

3. Methodology

3.1. Literature search strategy

As the value of hydrogen is an emerging topic, and research was conducted in diverse disciplines, we aim to identify relevant studies and synthesize them to identify value categories and, if possible, conceptualize a customer-oriented view of value. In this section, we mainly focus on "energy", "hydrogen," and "value" to try to answer our RQ1, "How is the value of hydrogen described in the published evidence?" by searching for the value of hydrogen in the B2B context.

Regarding that aim, we conducted an integrative literature review that reviews, critiques, and synthesizes representative literature on topics that experience rapid growth (Torraco, 2005). Such a review focuses on a topical area in previous studies, resolves inconsistencies, and generates new perspectives (Callahan, 2010; Torraco, 2016). An integrative literature review is recommended when an emerging phenomenon is presented in numerous sources related to different disciplines (Zorn & Campbell, 2006). The purpose of the integrative review is not to screen all articles that have ever been published but to draw on insights from different fields or research traditions and to address new topics (Torraco, 2005).

We followed Snyder's (2019) guidelines for an integrative literature review that combines perspectives from different fields, making it necessary to search for combinations for B2B, hydrogen, energy, and value. The steps procedure was designed to extract several concepts simultaneously: (1) prescreening and (2) scientific database search relationships. Following our research question, we analyzed and synthesized literature (Table 1 and Figure 2).

The scientific databases Scopus and Web of Science were used to identify original refereed journal articles and reviews in English (Torraco, 2016). It was highlighted that the term "value" related to hydrogen papers has different connotations and is many times related to technical values (numbers) or chemical properties of H_2 or related molecules (e.g., pH value). For this reason, most publications were found in specialized chemical and medical journals, and these papers were removed in the pre-screening stage. Then, in the second step, the documents using hydrogen AND value found in Scopus (58) and Web of Science - WoS (56) scientific databases were examined. When using (hydrogen AND value) OR (energy AND value), we found 21 papers in WoS and 25 in Scopus. There were no papers for hydrogen AND value AND ("business to business" OR B2B). The abstract and conclusion of the remaining papers were read, and relevant documents were selected. Every selected paper was reviewed to identify the definition or category of the value of hydrogen, its measurement, effects, and findings.

In some cases, additional representative works in the field had been referred from the found categories in case they provided specific examples of the category. The final sample comprises 43 papers published between 2006 and 2024, mostly in energy, engineering, and sustainability journals. It can be highlighted that no documents were found in business and marketing journals, and this is a critical gap considering the international efforts around the hydrogen economy development.

Table 1. Search strings in article's title and search results after prescreening (number of papers) – Search date: February 2024
(Source: Authors own work)

Search strings	WoS	Scopus
hydrogen AND value	56	58
(hydrogen AND value) OR (energy AND value)	21	25
hydrogen AND value AND ("business to business" OR b2b)	0	0

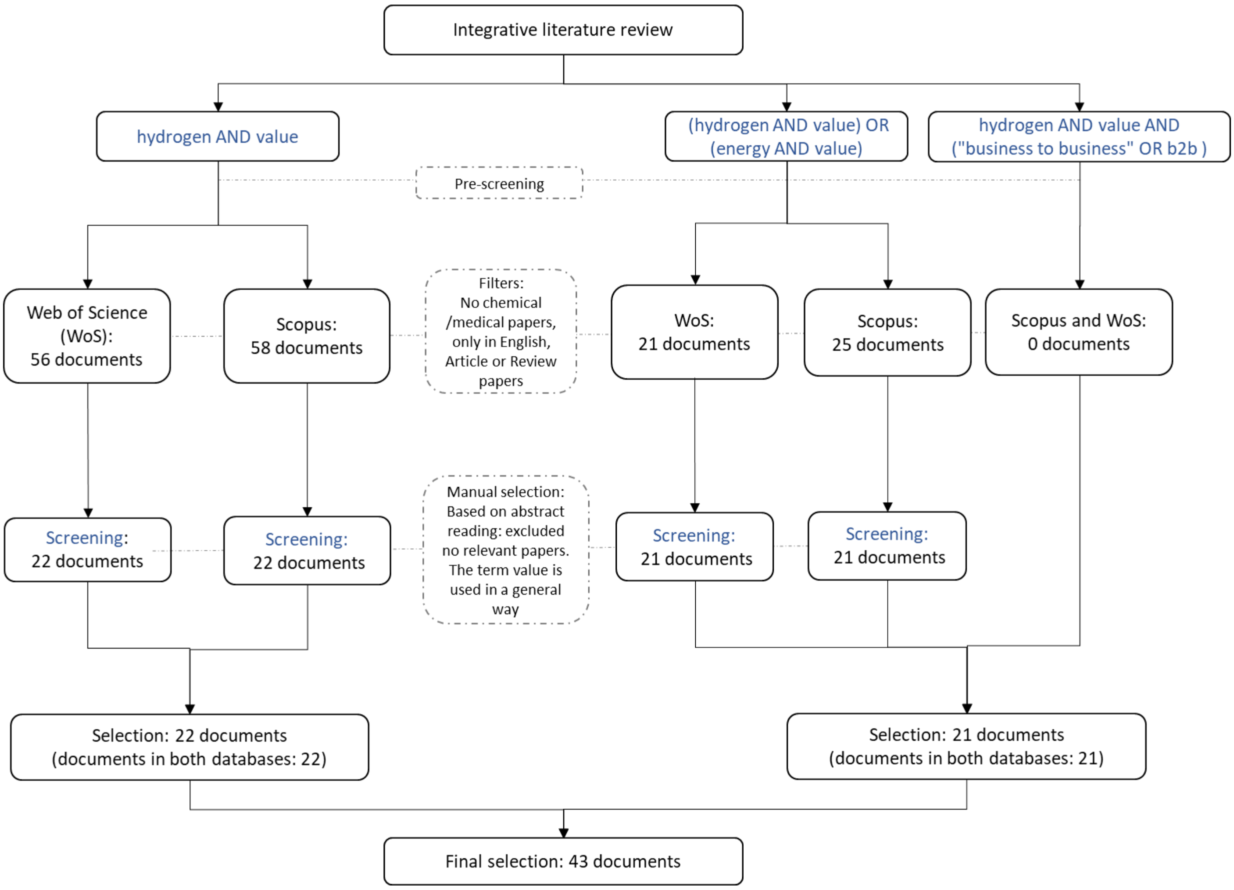

Figure 2. Flowchart of articles included in the literature review (Search date: February 2024) (Source: Authors own work)

3.2. The value of hydrogen: key categories in recent literature

Most H_2 studies take the product and supply chain perspective of value. In this sense, the findings from the integrative literature review are categorized in Table 2. They cover its aspects at the macro (e.g., global warming), mezzo (e.g., energy security), and micro (e.g., levelized cost) levels. Their common feature is the quantification and measurability of outcomes, mainly for H_2 fuel/feedstock products and, in some cases, for H_2 technologies.

Four value categories have been identified (Figure 3). The first relates to economic topics and examines value-added through the different transformations that follow the flow of goods in a value chain. It emphasizes the efficiency and effectiveness of the flow of tangible and intangible goods to the customer. Thus, the ability to reduce costs and keep costs under control is the key goal (Jääskeläinen & Heikkilä, 2019). The second relates to environmental aspects, in some cases considering the lifecycle of hydrogen products. The third one highlights social elements of value. Finally, the fourth identifies specific technical features of hydrogen technologies that can add value. Identified categories of the H_2 value are oriented to the product in Sections 3.3-3.6 but do not include the subjective approach of customers because, from the literature review, we could not find any reference explicitly presenting a discussion or tool on the perceived value of hydrogen for business customers. Thus, we recognize and propose alternatives for assessing value for business customers in Section 4.

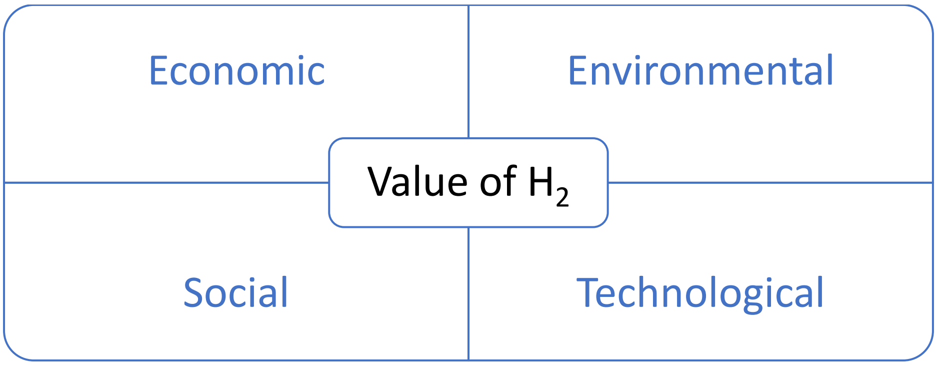

Figure 3. Categories of the value of hydrogen based on the current state-of-the-art

(Source: Authors own work)

Table 2. Dominant approaches to the value of hydrogen

(Source: Authors own work)

Categories of value	Elements of value	Measurement	Source
Economic	Total daily cost	Monetary	Almansoori & Shah, (2006); Quarton & Samsatli (2021)
	Levelized cost of hydrogen	Monetary	De-León Almaraz et al. (2022); Ochoa Robles et al. (2020); Törőcsik et al. (2020);Garcia-Navarro et al. (2023)
	Cost-benefit	Monetary	Chen et al. (2019); Xue et al. (2021)
	Net present value	Monetary	Fúnez Guerra et al. (2021); Samsatli & Samsatli (2018); Lim et al. (2021); Sabio et al. (2010)
	Revenue/benefit/ profit	Monetary	Samsatli & Samsatli (2018); Zhao et al. (2022); Liu et al. (2023)

	Total Cost of Ownership	Monetary	Cantuarias-Villessuzanne et al. (2016); Ochoa Robles et al. (2020); Ruf et al. (2020); Sun et al. (2010); De-León Almaraz et al. (2022)
	Market clearing price	Monetary	Akbarizadeh et al. (2023)
	Thermo-ecological cost	Monetary (based on ecological effects)	Mendrela et al. (2023)
Environmental	Global energy warming potential	CO_2-eq (weight)	Cooper et al. (2022); White et al. (2021); Hoffmann et al. (2023)
	Life-cycle assessment (LCA)	Several metrics	Wilkinson et al. (2023); Singh et al. (2023); Zhang et al. (2024)
	Circularity	Several metrics depending on the H_2 products or components of H_2 technologies	Yáñez et al. (2019); Chandrasekhar et al. (2020); Sustaincell.Eu (n.d.)
Social	Social acceptability	Customers' willingness to pay	Lim et al. (2021); Heo & Yoo (2013); Hoffmann et al. (2023)
	Social cost-benefit analysis (externalities)	Total socio-economic impact of the introduction of new fuels	Cantuarias-Villessuzanne et al. (2016); De-León Almaraz et al. (2022); Ochoa Robles et al. (2020)
	New Jobs	New of jobs Working conditions	Espegren et al. (2021); Werker et al. (2019)
	Social sustainability	There is no agreement on it. Two frameworks: (1) Social-Life Cycle Assessment; (2) Global Reporting Initiative: Human Rights, Labour Conditions, Society and Product Resp.	Eizenberg & Jabareen (2017); UNEP (2009)
	Awareness	Information availability, perception, and trust level	De-León Almaraz et al. (2023); Gordon et al. (2024)

Techno-logical	Flexibility	Value of curtailed hydrogen	Zenith et al. (2022); McCarthy et al. (2007)
	Energy storage	Can be coupled with renewable energy sources and store green energy Autonomy Energy security Energy imports	Samsatli & Samsatli (2019); McCarthy et al. (2007); Li et al. (2024); Boretti (2024); Hoffmann et al. (2023); IEA, Eurostat; McCarthy et al. (2007)
	Reliability	Technology readiness levels Reliability index Conditional value at risk	HYFINDR (2023); Boretti (2024); McCarthy et al. (2007); Rong & Kuang (2023)
	Safety	Physical security Risk index	McCarthy et al. (2007); Kim and Moon (2008);
	Energy transition	Materials criticality Circularity Energy transition	Abdelkareem et al. (2021); Sustaincell.Eu (n.d.); Egerer et al. (2024)

3.3. Economic value

This aspect of value refers to monetary units and can be quantified in the form of the total cost (Almansoori & Shah, 2006; Quarton & Samsatli, 2021), net present value (Fúnez Guerra et al., 2021; Garcia-Castro et al., 2022; Lim et al., 2021; Samsatli & Samsatli, 2018, 2019), revenue/benefit/profit (Samsatli & Samsatli, 2018; Zhao et al., 2022), cost-benefit (Chen et al., 2019; Xue et al., 2021), and more recently as the levelized cost of hydrogen (LCOH) (De-León Almaraz et al., 2022; Ochoa Robles et al., 2020; Törőcsik et al., 2020). The studies reporting the economic value usually include comparing energy market options or H_2 technologies (Carrera & Azzaro-Pantel, 2021; Parra et al., 2019). However, a few studies report the hydrogen price for specific markets (e.g., Lazard, 2021).

The first focus of this set of works is H_2 competitiveness, and a common conclusion is that renewable hydrogen produced via electrolysis is more expensive than conventional hydrogen (Parra et al., 2019). Moreover, transportation and distribution costs are also very high compared to supply chains for other fuels, such as oil and diesel (IEA, 2019). Two strategies are proposed to increase cost-effectiveness: (1) market growth (Velazquez Abad & Dodds, 2020) and (2) quantifying/adding the externality costs (Cantuarias-Villessuzanne et al., 2016). Although, for the former, industrials argue that governmental and social support is needed to deploy the infrastructure and that the demand uncertainty is an obstacle to increasing investment (POLITICO, 2021), some countries are already preparing to phase a change in demand in their territories, e.g., Norway (Espegren et al., 2021). For the latter, it is country-specific, and the definition of subsidies and the type of externality is still needed, but according to Ajanovic et al. (2022), if including all external costs of all energy carriers, hydrogen of any color may become economically competitive in any sector of the energy system. For this purpose, the coordination of stakeholders is critical, as well as the development of a new subsidy policy for hydrogen products (Tuofu et al., 2022).

3.4. Environmental value

The influence of hydrogen use on the environment also constitutes an element of value. Traditional metrics of the environmental value are $CO_{2\text{-eq}}$ emissions (Cooper et al., 2022; Quarton & Samsatli, 2020; White et al., 2021), also expressed as the global warming potential (Garcia-Castro et al., 2022). There is an associated environmental benignity (value) to the different colors of hydrogen (Velazquez Abad & Dodds, 2020). Although H_2 is colorless, it has become increasingly popular to use color labels to distinguish the carbon emissions of related energy sources, different technologies, and raw materials used for its production, distribution, and transportation (life cycle assessment). However, there is also a debate about what can be categorized as “green” H_2 (e.g., RFNBO). Some reports use this label for low-carbon hydrogen independently of the technology used, and others use it to refer to renewable energy sources and electrolysis (Velazquez Abad & Dodds, 2020). For industries using gray H_2, adding Carbon Capture and Storage (CCS) technology is also being explored to decrease the environmental impact (Cooper et al., 2022). In this case, blue H_2 is produced. Still, the cost of CCS should be included. Another development aspect is the regulatory framework (Velazquez Abad & Dodds, 2020). This point can be critical regarding traceability and trust because consumers should be able to verify that the carbon emissions of H_2 they buy are correct (e.g., the value of green H_2) and ensure they are paying what is fair. Hydrogen used in flexible energy systems or industrial processes could not be certified without a guarantees of origin (GO) scheme. In this sense, certificates and GOs are being developed to track the impact of the hydrogen supply chain and report the final product's proper framework (Velazquez Abad & Dodds, 2020). This point is essential, and in case externalities are included in the economic calculations, they have to be accurately associated with the carbon costs (White et al., 2021) (e.g., European Union Emissions Trading System (EU ETS)). The value of the GO certificates influences the value of H_2. Policies affecting these factors will impact the evolution of the green hydrogen market. However, as green hydrogen GOs are voluntary, the market is tiny, and their value is deficient. At the initial stages of market development, allowing double compensation of GO and other incentives could positively impact market growth (Velazquez Abad & Dodds, 2020).

The environmental aspect is always related to net-zero strategies, zero-emission technologies, regulatory and certification schemes, and eco-friendly products (Heo & Yoo, 2013). This is used as a strong advantage of H_2 and is a common argument in the public debate. It is also used as a justification to approve financial support of international projects aligned to support sustainability guidelines (European Commission, 2022; IRENA Coalition for Action, 2021). Formal Life Cycle Assessment methodologies can provide helpful information to business customers about the environmental footprint of hydrogen products. Circularity issues are also related to producing hydrogen feedstocks or hydrogen technologies like fuel cells or electrolyzers due to using some critical and scarce materials (Sustaincell.Eu, n.d.).

3.5. Social value

The definition and measurement of social value elements are more complex than the previous criteria, and the attitude, perception, and expectations about hydrogen become more critical. In the literature review, the aspects related to social value are reported at different levels. The first is social acceptability, measured through the customers' willingness to pay, e.g., hydrogen fuel produced from waste (Lim et al., 2021), hydrogen fuel cell buses (Heo & Yoo, 2013) or, hydrogen cars in the context of green buying (Chen & Zhang, 2021). These studies employ qualitative research, use questionnaires and surveys, and, in addition to the definition of acceptability questions, collect socio-demographic data such as income and gender while collecting the customers' acceptability.

Next, the social cost-benefit analysis can integrate both economic and environmental aspects. Through this analysis, decision-makers can compare technologies and measure the total socio-economic impact of introducing new fuels (Cantuarias-Villessuzanne et al., 2016; Ochoa Robles et al., 2020). It also allows the calculation of needed incentives and subventions (to develop new policies and regulations). Additionally, there is a need to understand the impact of the energy transition on job losses and creation (Espegren et al., 2021).

Macroeconomic and geopolitical aspects are also discussed concerning the social system and not necessarily to the business customers (e.g., energy equity (World Energy Council, 2019)). These aspects could be integrated into larger frameworks. e.g., social sustainability (Eizenberg & Jabareen, 2017). To our knowledge, that approach has yet to be applied in hydrogen studies. However, information availability and social awareness could influence the potential users' perception (De-León Almaraz et al., 2023; Gordon et al., 2024).

3.6. Technological Value

Several aspects related to the technological value of hydrogen products were identified. (1) H_2 provides flexibility due to the many alternatives for energy sources, production methods, and final conversion technologies (Törőcsik et al., 2020); (2) H_2 can store energy (energy carrier) and can stabilize wind and solar market values (Ruhnau, 2022); and H_2 could contribute to the autonomy and energy security of the countries (decreasing energy imports). (3) For reliability, some hydrogen technologies are currently under development and might display improved efficiency. Technology readiness levels can help decision-makers select H_2 products. In this sense, McCarthy et al. (2007) propose using a reliability index to evaluate the hydrogen supply chain. (4) Safety is a critical technological aspect that might affect the public perception of H_2 technologies, and (5) H_2 technologies will compete with other technological efforts for the energy transition. A straightforward way to compare energy technologies could help in purchasing decisions.

3.7. The value from the perspective of business customers

Based on the literature review, we needed to find information about value from the business customer's perspective. There are several arguments for developing research around the concept of the value of hydrogen.

First, hydrogen is related to several products (Section 2.2), and even as a fuel is not homogenous, different types of hydrogen (using colors or carbon impact) can be produced from various primary energy sources, transferring differences in costs and related emissions. Buyers must go into detail to compare types of hydrogen fuels or technologies to other products.

Second, a multicategory approach to value can help understand sustainable aspects that might be decisive for some customers, even if hydrogen has a lower economic value today (higher price) than fossil fuels. Taking a narrow understanding of value affects the comparison of hydrogen with other fuels to cost-effectiveness alone, which limits the possibility of attracting a wide range of business customers to hydrogen (Apostolou & Xydis, 2019). Some buyers can value acceptability, social aspects, or environmental issues more than monetary value (Flynn et al., 2009).

Third, the growing demand for green fuels in many sectors needs a framework that supports explaining the value from the perspective of various customers and other actors (Fúnez Guerra et al., 2021).

Fourth, as business customers assess value based on their experience, the perceived value is contextual, dynamic (Corsaro & Snehota, 2010), and subjective (Bischoff et al., 2023). B2B marketing literature calls for a better understanding by suppliers of how their customers conceive and measure value (Flint et al., 2011; Ulaga & Chacour, 2001) and for a framework to analyze, communicate, explain, and compare the value of their complex offers proposed to customers (Keränen & Liozu, 2020; Wengler et al., 2020). To the best of our knowledge, there is no information on how business customers can measure and compare the value of H_2 products vs other alternatives by considering their needs, goals, and perceptions. With this in mind, in Section 4, we address how business customers can measure and compare the value of H_2 products vs. other alternatives.

4. Multicategory guideline for H_2 value assessment for business customers

The literature review on the value of hydrogen indicates that it is dominated by the perspective of the product delivered to the customer and the chain that supplies it. It mainly highlights the economic and environmental, less often social, and technological criteria of the value of hydrogen. This approach presents value through the prism of objective elements that can be quantified and measured. However, B2B marketing literature understands the value perceived by business customers as complex, multidimensional, subjective, and differentiated among members of the same organization. Therefore, this section expands the view of hydrogen by addressing the literature synthesis with conceptual B2B marketing lenses.

Our initial assumption is that potential customers are often presented with a partial or unclear value of hydrogen. This ambiguity might significantly impact companies' perceptions of hydrogen (fuel or product) when considering its purchase. To answer how business customers can measure and compare the value of H_2 products vs. other alternatives, we propose the multicategory guideline for assessing the value of hydrogen products for business customers (VH_2-BC).

To develop that guideline, in Table 3, we link three dimensions: 1) the product-oriented value categorization identified in the literature review, 2) the elements of B2B value (Almquist et al., 2018), and 3) the concept of goal-oriented value proposed by Kleinaltenkamp et al. (2022).

As presented in Section 3, Figure 3. and Table 2., the first dimension has four generic value categories: economic, environmental, societal, and technological.

For the second dimension, we operationalize goals based on the value architecture proposed by Almquist et al. (2018). This way, we follow Beitelspacher and Getchell's (2023) conceptualization of value based on elements suggested by Almquist et al. (2018). We also respect the advancements of B2B by Matthyssens (2019) in recognizing individual and collective actors in business customers and differentiation of the elements of B2B offerings that were studied by several researchers (Kienzler et al., 2021; Latinovic & Chatterjee, 2024; Mai & Liao, 2022) based on Almquist et al. (2018) B2B value concept. This architecture of value consists of the following components for a collective customer: meeting table stakes (meeting specifications, acceptable price, regulatory compliance, and ethical standards); functional value derived from economic improvements (improved top line, cost reduction), and higher performance (product quality, scalability, innovation); enhanced ease of doing business thanks to improved productivity (time savings, reduced effort, decreased hassles, better information, transparency), higher operational benefits (better organization, simplification, better connection, higher integration), better access (product/service availability, configurability, and variety), more beneficial relationships (supplier responsiveness, expertise, commitment, autonomy, cultural fit), strategic benefits (risk reduction, better market reach, higher flexibility and ability to supply higher quality products). The value for individual decision-makers derives from supporting the professional development of individuals by meeting personal expectations (meeting design and aesthetic needs, helping in personal development, reducing anxiety, giving enjoyment opportunities) and supporting careers (expanding professional network, improving individual marketability, assuring reputation). The last element of individual value can be built by inspiring some individuals in an organization (for hope, social responsibility, and vision) (Almquist et al., 2018).

The third dimension consists of collective and individual goals and the extent to which these goals are achieved. Adding this dimension, we follow the recent discussion that value for business customers is motivated by the customer’s goal system (Bischoff et al., 2023), which Sairanen et al. (2024) applied to define value dimensions in the circular economy. This dimension has two categories. First, the goals represent a “mental image or other endpoint representation associated with effect toward which action may be directed” (Pervin, 1989). They are founded on users’ attitudes, emotions, norms, and desires (Kleinaltenkamp et al., 2022). Anticipated goals refer to the expected value in use built on promises and offers communicated by different suppliers. Goals explain why the customer wants to achieve a particular outcome and how the customer can achieve the desired result (Bagozzi & Dholakia, 1999). We define goals using a standard managerial operationalization: minimize/reduce, maximize/increase, or maintain/stabilize (Slack & Brandon-Jones, 2019). These goals are generic and can be applied to any energy product. The second category of goal-oriented value is built by the degree of goal achievement (Kleinaltenkamp et al., 2022; Woodruff, 1997). That degree defines value, so achieving the goal thanks to an H_2 product or H_2 supplier means high value. We include in the guideline measurement of value by pointing out questions that assess the proximity to goal achievement thanks to selecting this energy product (Huber & Kleinaltenkamp, 2023; Kleinaltenkamp et al., 2022). The connection of value categories of hydrogen, the concept of goal-oriented value, and elements of value are presented in Table 3.

Table 3. Conceptualization of the multicategory guideline for H_2 value assessment

(Source: Authors own work)

Generic category of value (literature review)	Elements of B2B value (Almquist et al. 2018)	Customer-oriented value (Kleinaltenkamph et al 2022)	
		Customer goals	Proximity of goal achievement
Environmental Economic Social Technological	For collective customers: table stakes, functional value, ease of doing business For individual customers: values, inspirations	Goals to be achieved thanks to H_2 in each generic category of value regarding elements of B2B value	Questions to identify the value of H_2 for a customer by measuring the extent of goal achievement.

The outcome of these conceptual efforts is the development of a guideline for H_2 value assessment for business customers. The conceptualization presented in Table 3 is developed in Table 4 to offer a list of detailed goals and questions to measure value for the business customer. This represents the multicategory guideline for assessing the Value of H_2 products for Business Customers.

Table 4. Multicategory guideline for assessing the Value of Hydrogen products for Business Customers (VH_2-BC guideline)

(Source: Authors own work)

1. Generic category of value	**2. Elements of B2B value**	**3. Customer goals** *Our goal is to buy energy…*	**4. Proximity of goal achievement** *To what extent does this hydrogen product…*

A. Environmental	meeting table stakes	… that maximally meets our specifications and regulations.	… meet environmental specifications and regulations on Global Warming Potential, Life-cycle assessment, and circularity?
	functional value	… that maximally commits to sustainability and reducing environmental impact.	… help the customer's employer branding relate to sustainability and environmental neutrality?
	ease of doing business	… from a supplier that is maximally responsive to our needs. … that increases our access to partners that await a sustainable approach.	… supplier is responsive to the customer's needs? … provide the customer access to partners that await sustainable approach?
	individual values	… that reduces the anxiety of my employees thanks to their contribution to fighting climate change.	… help the customer to reduce its employees' anxiety thanks to the contribution to fighting climate change?
	inspiring	… that maximally supports the creation of a vision of our company. … that increases hope for a better world. … that is maximally sustainable.	… help the customer to create its vision? … give hope for a better world to customers' employees? … provide the feeling of being sustainable to the customer's employees?
B. Economic	meeting table stakes	… at an acceptable price.	… has a price (cost/levelized cost/total cost of ownership/net present value) acceptable for the customer?
	functional value	… that increases our top line. … that reduces our costs. … that maximizes our ability to supply higher quality products to our customers.	… generate additional revenue/benefit/profit for the customer? … reduce daily cost/levelized cost/total cost of ownership/net present value for the customer? … enable the customer to supply higher quality products to its customers?

	ease of doing business	… that maximizes our ability to expand to an additional demand or to operate in new locations or market segments. … that maximally supports our innovativeness. … that reduces our time and/or efforts. … that maximally supports better organization or simplification of our operations. … maximally available when and where needed. … that can be maximally adapted to our needs.	… allow the customer to expand to an additional demand or open access to new locations or market segments for the customer? … support innovativeness of the customer? … save the time or/and efforts of the customer? … help the customer in better organization or simplification of operations? … increase the availability of energy for the customer? … subjects to configuration to the needs of the customer?
C. Social	meeting table stakes	n/a	n/a
	functional value	n/a	n/a
	ease of doing business	… that lets us decrease hassles. … that lets us increase transparency. … from a supplier that maximally provides us with relevant knowledge. … from a supplier that is maximally committed to our development. … from a supplier that increases our autonomy. … from a supplier that maximally fits us in terms of culture. … from a supplier that increases the knowledge of our employees.	… decrease customer hassles? … help the customer to be more transparent? … supplier can share valuable knowledge with the customer? … supplier can commit to the customer's development? … supplier give the customer more autonomy? … supplier culturally fit to the customer? … supplier that enriches the information of customer's employees?

	individual values	… from a supplier that maximally makes our company an enjoyable workplace. … from a supplier that increases the expansion of individual buyers' professional networks. … from a supplier that increases our employees' experience. … from a supplier that increases our employees' reputation.	… supplier helps the customer to provide enjoyment opportunities to the employees? … supplier helps the customer's employees to expand their professional network? … supplier helps the customer's employees to gain experience from new projects? … supplier helps the customer's employee to build their reputation?
	inspiring	… from a supplier that increases our social responsibility. … that increases our ability to perform our activities ethically.	… supplier helps the customer's employee to be socially responsible? … help the customer perform ethically?
D. Technological	meeting table stakes	… that maximally meet our specifications and regulations.	… meet industry-specific specifications and regulations?
	functional value	… maximally available when and where needed … of high reliability and stability.	… increase the availability of energy for the customer? … supply the customer with reliable energy?
	ease of doing business	… that reduces our risk by higher diversification of energy sources and lower reliance on fossil fuels … from the source that increases our connection to a valuable and safe supply chain. …that increases integration of different facets of the business. … that increases our autonomy with a better energy mix.	… help the customer to reduce the risk by higher diversification of energy sources and lower reliance on fossil fuel? … supplier connects the customer to a valuable and safe supply chain? … support better integration of different facets of customer's business. … provide a better energy mix to the customer?
	individual values	… from a supplier that maximizes our forward-thinking.	… supplier helps the customer to be a more innovative and forward-thinking workplace for its employees?
	inspiring	… that, thanks to its technology, increases our ability to perform our activities ethically.	… help the customer perform ethically?

5. Discussion

In this study, we aimed (1) to identify key value aspects of H_2 and (2) to identify or propose specific tools that allow the measurement of the value of H_2 for business customers. The first objective was achieved through the development of the literature review. We recognized that the value of hydrogen is described in a multidimensional way that includes economic, environmental, social, and technological aspects. The value of hydrogen is presented mainly as a quantifiable feature of H_2 products, is presented partially, and lacks elements related to perceived value evaluation for business customers. As previously justified, perceived value can be crucial in decision-making and represents a significant scientific and business gap.

For that reason, our second objective resulted in the main contribution of this paper: the proposition of a tool that attempts to assess the value of H_2 products by business customers. We developed a multicategory guideline for H_2 value assessment for business customers. The VH_2-BC guideline integrates the pillars of sustainability and technological elements of value into marketing concepts and frameworks to consider the Business Customer's goals. The combination of different approaches makes this proposal original and unique. We identified a list of generic desires related to the fuel a company might need to evaluate. It adds a business customer perspective to the up-to-date value concepts of H_2.

The VH_2-BC guideline extends the idea of the value of hydrogen considered in the literature by adding new elements connected to a strategic perspective (Nailer et al., 2019). It shows that customers could perceive the value of hydrogen from the angle of productivity and operational benefits. They can also link it to long-term goals like expansion, building new relationships, and looking for stability. It includes the reliability of energy supplies linked to organization stability and access to trustworthy suppliers of a balanced energy mix to pay attention to the quality of the resource integration process (Bischoff et al., 2023). The strategic perspective also incorporates elements related to sustainability: new opportunities for accessing customers that look for green offers, attracting employers sensitive to workplace sustainability that can be linked to environmental human-resource management initiatives (Pham et al., 2019), etc. Putting together the pieces of studies, this paper can enrich the multicategory analysis of H_2 value conducted so far by connecting the multicategory elements for product-oriented value to the elements of the customer-oriented value, as displayed in Figure 3 and Table 2.

In addition, the value of sustainability (from the marketing perspective) was not explicitly considered for hydrogen products. This constitutes another vital contribution to our work. Using the VH_2-BC guideline, the user can have a quick overview of the more potent and weaker points for hydrogen when the sustainable criteria are put together. Today, a classic trade-off exists between cost and environmental impacts (Guillén-Gosálbez et al., 2010). Still, some social aspects can be in synergy with the environmental effects (e.g., minimization of safety risk and CO_2 emissions (De-León Almaraz et al., 2022)).

This paper also pays attention to the needs and goals of individuals working in companies, which allows for addressing a more comprehensive range of stakeholders than only executive decision-makers in supplier-customer dyads (Kowalkowski et al., 2016)**.** We support an in-depth discussion on hydrogen from the value-in-use perspective, as it shows how companies could benefit from buying and consuming hydrogen. Due to climate change, the cost of energy as the only selection criteria might need to be more convincing for individuals in organizations with a transforming or initiative approach (Francoeur et al., 2021). Therefore, we need to understand how collective desires and goals are caused by individual desires and goals on energy and vice versa - how collective desires and goals influence individual desires and goals on energy in organizations.

As these elements of value conceptually derive from the desires and goals of individual and collective customers in organizations, the idea of the value of H_2 for business customers highlights the micro perspective. However, it omits several aspects of the hydrogen ecosystem considered on mezzo on macro levels (e.g., the external cost for building and maintaining H_2 infrastructure). Thus, the suggested concept enriches the approach to the value of H_2 but does not replace any of the aspects discussed in the Economic/Environmental/Social/Technological framework.

Our approach presents some limitations: 1) the proposed guideline takes into account the current state of the art and the ideas from the authors with their knowledge and experience, 2) the tool requires validation, 3) the evolution of the hydrogen economy might require updates in the value elements listed in the guideline. Although these limitations exist, our work also presents an original perspective that can be more approachable in a business context by taking into account a promising energy carrier like hydrogen from which collaboration and information are needed for different stakeholders displaying a real need to have reliable and effective assessment tools for industrial and business customers.

6. Conclusion

This paper has discussed the different value perspectives in business-to-business (B2B) literature. We provided a general overview of the hydrogen supply chain and product types. The most treated elements of the hydrogen value have been identified using an integrative literature review. We have discussed how the value of hydrogen could be understood or measured by business customers, and finally, we have proposed specific tools for that purpose. It can be highlighted that no documents were found in business and marketing journals, and this is a critical gap considering the international efforts around the hydrogen economy development. We proposed a novel multicategory guideline for assessing the Value of Hydrogen products for Business Customers (VH_2-BC guideline) that considers sustainability and business customers' perspectives. This tool does not substitute other quantitative measures of value but complements the assessment by matching the hydrogen product's features to the customer's needs.

6.1. Key theoretical contributions

The critical theoretical contributions of the study are (1) identification of key categories of H_2 value, including social and technological aspects to the discussion that is dominated by economic and environmental categories; (2) building a bridge to business-to-business literature by taking a business customer perspective on H_2 value; and (3) conceptualization of the multicategory guideline for H_2 value definition from a business customer perspective.

This study synthesizes and extends the understanding of the value of hydrogen for business customers by highlighting that the value of H_2 for business customers should include technological and reliability aspects (Zenith et al., 2022). By connecting the energy, engineering, and sustainability discourse with the business-to-business marketing concept of value, we add strategic aspects to the value of H_2. We relate them with achieving the long-term goals of purchasing companies and their employees' values. Considering them as elements of value enriches the concept of value in use for business customers and counterbalances some short-term, operational aspects of value.

This study contributes to the discussion on the value of sustainable energy by offering a business customer-centric perspective. Most literature considers the value added to the H_2 product by companies in a supply chain but omits the customer's view of value. Even if Beske-Janssen et al. (2023) report on the importance of supply chain sustainability for buyers in the next 20 years, other researchers pointed out difficulties in translating those aspects of value to customer benefits (Ramirez et al., 2014). Business customers try to avoid the uncertainty of H_2 suppliers' offers (Knight et al., 2015), are confused when measuring the sustainability of business offerings (Kapitan et al., 2019), and seek reputational benefits rather than only price (Kienzler et al., 2021). Our work points out the need to understand the value of H_2 from the perspective of the goals of individuals and organizations (Kleinaltenkamp et al., 2022; Macdonald et al., 2016) and their experience in the purchasing and usage processes (Becker et al., 2023) regarding specific B2B elements of value (Almquist et al., 2018).

This study also conceptualizes the multicategory definition of H_2 value (VH_2-BC guideline). It offers detailed guidelines for identifying elements of value related to four generic categories and assessing the value of hydrogen products for business customers by determining their goals and to what extent hydrogen products help them achieve them.

The originality of our work also stems from introducing hydrogen topics into empirical contexts of the B2B literature. This literature recently discussed the complexity of sustainable fuel and energy offers but took mostly suppliers' points of view (Rawat & Garg, 2023). Our paper points out the deployment of green hydrogen supply chains, identifies currently used categories of hydrogen value, and proposes an entirely new and original guideline to introduce the aspects of value from the business customer's perspective.

6.2. Practical implications

To the best of our knowledge, there is a gap concerning a tool for business customers that could be useful in analyzing, communicating, explaining, and comparing the value of hydrogen and easing decision-making (Keränen & Liozu, 2020). Bridging the significant discussion on H_2 with the achievements of B2B literature on understanding value, this paper identifies critical value aspects of H_2. It integrates them into a tool that allows the measurement of its value.

This study suggests that customers perceive the value of resources if they benefit by using them (McColl-Kennedy et al., 2012) to fulfill their goals (Kleinaltenkamp et al., 2022). As a result, this paper offers the guidelines for the value of H_2 for business customers (VH_2-BC). It points out the interconnections of value categories with elements of value of H_2 as a fuel/product and elements related to H_2 suppliers and benefits expected by collective and individual customers. This tool can be applied to multidimensional measurements of the value of H_2 and comparison with other energies. It also offers detailed suggestions for building value propositions for renewable energies. Thus, the guideline answers the call for methodological support for value-based discussions on replacing old fuels with new ones (Ranta, 2020).

The VH_2-BC guideline offers industrial companies' purchasing functions a tool for assessing the value of H_2 when they buy it. By opening the discussion of H_2 value perception from the purchasing perspective, the concept introduced in this paper allows buyers to analyze how H_2 products rank vs. other products/competitors. Through this frame, the decision maker could justify the decisions by listing the advantages of hydrogen through a multi-criteria framework as a prerequisite for multi-criteria decision-making.

Our proposal allows for considering the relative value of hydrogen due to the subjectivity involved in the user's perception. It is also highly recommended that the guideline for comparing hydrogen products to at least one hydrogen product's competitor be applied. For example, for a logistics company interested in evaluating the value of hydrogen buses, it would be relevant to compare them to diesel and electric buses using the VH_2-BC guideline.

As a first step, the business customer or buyer must clearly define the hydrogen product subject to be evaluated and compared. Second, select the goals listed in the guideline that align with the company's goals. Third, answer the listed questions for hydrogen products and hydrogen products' competitors using a scale of 6: Not at all, Minimally, Partially, Moderately, Largely, Completely. The next step consists of the analysis of the results. Fifth, identify if other elements of value should be part of the evaluation and, if so, add them to the guideline and repeat the assessment from step 2. When all the elements of value have been evaluated for all the categories, it is possible to define the subjective value of hydrogen products (and other alternatives, if applicable) for this specific customer by considering the multicategory approach connected to their particular organizational and individual goals. An example of the application of the VH_2-BC guideline for understanding the value of the H_2 bus compared to the diesel bus is presented in Table 5. This might also have commercial implications.

Table 5. An exemplary application of VH_2-BC guideline to compare the value of products

(Source: Authors own work)

1. Generic category of value	**2. Elements of B2B value**	**3. Customer goals**	**4. Goal achievement**		
			Proximity assessment	**H_2 bus**	**Diesel bus**

A. Environmental	meeting table stakes	Our goal is to buy energy that maximally meets our specifications and regulations.	To what extent does this product meet environmental specifications and regulations on Global Warming Potential, Life-cycle assessment, and circularity?	moderately	minimally
	functional value	We aim to buy energy that maximally commits to sustainability and reducing environmental impact.	To what extent does this product help our employees' branding relate to sustainability and environmental neutrality?	largely	minimally

For energy suppliers' marketing and sales functions, the guidelines are suggested for building their value proposition for business customers. Addressing detailed customers' goals opens opportunities for indicating the sustainable value of renewable fuels. For example, building H_2 awareness might affect social acceptability, and better-informed managers can have a new perception of H_2 fuel. That can be useful when different aspects of value are conflicting in the eyes of purchasing organizations, like in the case of sustainability and strategic aspects vs. short-term benefits (Beske-Janssen et al., 2023). Marketing and sales practitioners could use our findings to connect their offerings to customer's needs and overcome the challenges in communicating the value that they face in many industrial companies (Bischoff et al., 2023). Specifically, they can use it to separate the value of hydrogen from economic efficiency and to present its different attributes to explain the value-in-use.

This research may also have a social impact by explaining the multiple hydrogen value categories, including sustainability. Regarding this technology's implementation and future development, engineers and scientists in that field are critical players in reshaping its understanding before being successfully commercialized. The guidelines presented in this paper can support education and raise awareness of the multicategory value of H_2 for business customers. Taking on the various roles, positions, and cognitive capabilities of people working in companies, they might not intuitively understand it.

6.3. Avenues for further research

As a conceptual work, this paper has some limitations typical for speculative studies and intentionally opens some avenues for further research. First, there is a challenge regarding the customers' awareness of the different types of H_2. Our considerations were somewhat general, and researchers could use them to distinguish between the values of various hydrogen products. Today, efforts are being made to clarify the concept of "green hydrogen" and other colors. In

February 2023, the European Commission provided new options for labeling products produced by H_2 technologies following a specific path in the hydrogen supply chain (Gregor, 2023).

Second, our work is conceptual, suggesting a guideline for a comprehensive understanding of value but not validating it. Testing our proposition with business customers could help develop this concept and collect empirical data presenting which benefits associated with hydrogen foster its acceptance, similar to the study by Hoffmann et al. (2023). Multi-criteria decision-making tools could also be applied to identify the best trade-off solutions among several value metrics (Ren et al., 2007).

Third, our work does not include the time and space dimensions of the value of H_2. As the value-in-use is continued, redefined, and improved through the value-adding practices of both the supplier and the customer (Macdonald et al., 2016), the value of H_2 should be linked to the state of the market development. As a new fuel, its value and potential can significantly differ in time. Previous works demonstrated the relevance of having multi-period and multi-scale analyses to capture the evolution of H_2 technology (constantly evolving) and the energy context (De-León Almaraz et al., 2013, 2015, 2022). Development of the value of H_2 in space dimension could take a broader view of the supply chain, network, or ecosystem. The idea of the value of H_2 for business customers could be developed on the assumption that business actors in a network undertake goal-directed actions to integrate resources, not only for their outcomes or benefits for the customers but also to develop the network collaboratively (Aarikka-Stenroos & Ritala, 2017).

Finally, further research can be developed to understand the effects of applying the proposed guideline with potential impacts on hydrogen acceptability.

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