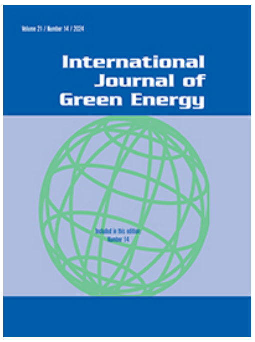

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# Achieving net zero-emission production through hydrogen: Evidence from Scottish whisky industry

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**ABSTRACT**

Climate change poses a significant threat to economic development and necessitates immediate action to achieve net-zero greenhouse gas emissions. This study investigates the feasibility of hydrogen systems as a comprehensive solution for decarbonizing the distillery industry, a sector often deemed “hard-to-treat” from service perspective. Through a qualitative case study of a whiskey distillery in Scotland, insights from senior management at both the distillery and the hydrogen system provider reveal the potential of hydrogen to not only serve as an energy source but also to address broader sustainability challenges within the food and agriculture sector. While advantages are evident, the study also identifies challenges related to infrastructure, cost, and the need for shifts in government policy, user attitudes, and investor perspectives. This research serves as a precursor to broader sectoral studies aimed at developing pathways toward net-zero emissions, emphasizing the importance of collaboration among stakeholders to unlock the full potential of hydrogen as a transformative solution for achieving a sustainable future.

**KEYWORDS**
Decarbonization; hydrogen; net-zero emission; whiskey industry

## 1. Introduction

Climate change has become one of the biggest global concerns and threatens economic development (Bataille 2020; Davis et al. 2018; Sofuoğlu and Kirikkaleli 2023). To cope with it, the international society has set the target of reducing global temperature by 2°C by the end of this century, in compliance with the Paris Agreement (Runsen et al. 2022). That commitment was strengthened at the 26th United Nations (UN) Climate Change Conference (COP-26) in 2021, when the major economies agreed to reduce carbon emissions and eventually achieve net-zero emission targets in 30–40 years (UN 2021). At the local level, both the Scottish and the UK governments have set ambitious zero-emission targets to be achieved by 2050 (UG n.d..). Net-zero emission, being defined as reducing the impact of society on the climate and environment (Runsen et al. 2022; UN 2018) is critical for the achievement of UN’s sustainable development goals (SDGs).

The energy sector has traditionally been the primary focus of emission reduction efforts, necessitating a significant expansion of clean energy sources (ETC 2021). However, recent attention has increasingly shifted toward “hard-to-treat” sectors, including the food and agriculture sector (Davis et al. 2018; Fankhauser et al. 2022). While zero-emission solutions are being developed for these sectors, they remain costly and in their early stages of development (Fankhauser et al. 2022).

Within this context, the whiskey industry significantly contributes to both the Scottish and UK economies. It represents the largest food and drink sector in both regions, accounting for 77% of Scottish food and drink exports and 26% of the total UK food and drink exports. In 2022, the industry contributed £7.1 billion to the Gross Value Added (GVA) of the UK (SWA 2024). However, as one of the largest spirit producers globally, it also faces the challenge of intensive greenhouse gas emissions generated throughout its production, storage, and transportation processes.

As Figure 1 shows, the spirit sector in the UK produces 530,000 tonnes of CO2 equivalent in 2018, higher than any European country other than Poland (Angleitner et al. 2021), due to its reliance on fossil fuels for distillation (UG n.d..). The largest driver of spirit-related emission is energy (Angleitner et al. 2021). In Scotland, a total of 148 distilleries consumes 3.7 Terawatt hours (TWh) of energy every year, accounting for 10% of total energy in Scotland (SDI 2024). Therefore, decarbonization of the Scottish whiskey industry by shifting to green energy is critical for both the Scotland and the UK to achieve their zero-emission targets (Früh et al. 2021; SG 2021).

Hydrogen has emerged as a potential solution for achieving net-zero emissions. It serves not only as a green energy source but also as a versatile energy carrier that facilitates other decarbonization approaches (Dodds et al. 2015; IEA 2019b; Ruth et al. 2017; Staffell et al. 2019; van der Spek et al. 2022). However, widespread adoption of hydrogen for energy on a large scale is hindered by barriers such as high costs, safety concerns, and unstable supply (Antonini et al. 2020; Bødal et al. 2020; EC 2020; van Cappellen, Croezen, and Rooijers 2018; van der Spek et al. 2022).

This challenge resonates across other manufacturing sectors, highlighting the need for net-zero solutions implemented at regional and national levels (Bataille 2020; Bistline and Blanford 2021; Davis et al. 2018). The Scottish whiskey

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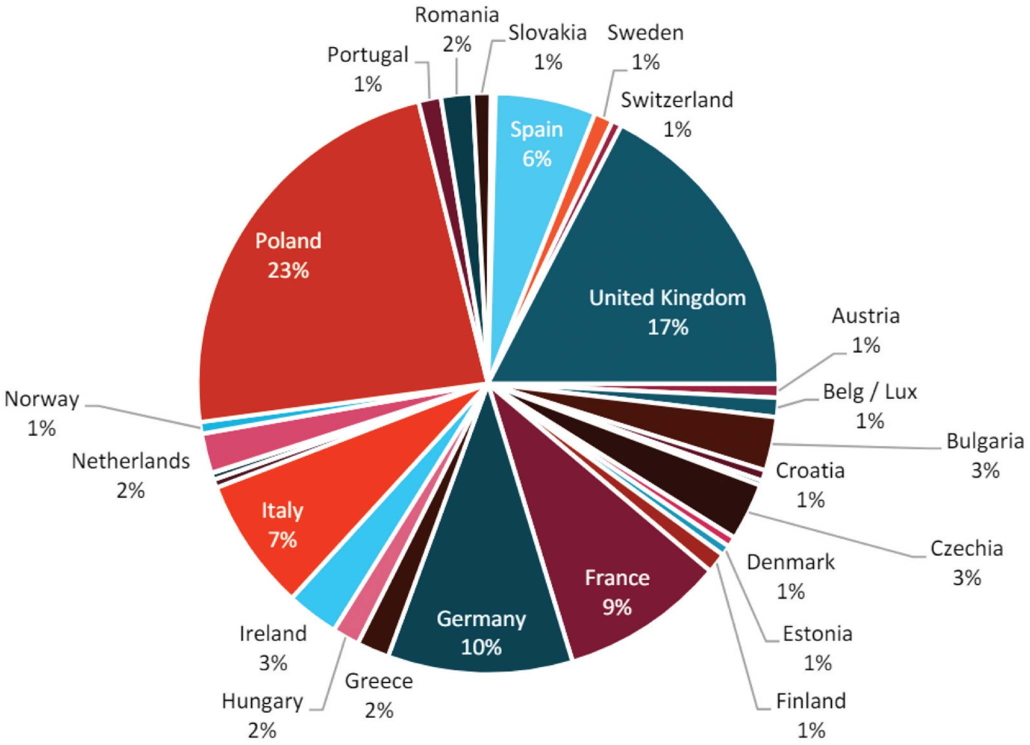

Figure 1. CO2 equivalent emissions of spirit industry by country. Source: Angleitner et al. (2021)

industry, for instance, has committed to achieving zero emissions by 2040, a decade ahead of the government's target (Fraser 2021). As depicted in Figure 2, multiple pathways have been identified to decarbonize whiskey production, utilizing various approaches such as anaerobic digestion, biomass, heat pumps, and hydrogen. Notably, hydrogen is estimated to potentially contribute to 19% of emission reductions, surpassing the other three technologies (Raphael 2020). Despite its significant potential in mitigating carbon emissions, the adoption of hydrogen by the whiskey industry remains in its nascent stage (Rennie 2023).

The successful implementation of hydrogen and its associated systems necessitates a multi-faceted approach that transcends mere technological advancement. It requires a confluence of political support, collaborative infrastructure development, effective policy frameworks, market design, and innovative business models (van der Spek et al. 2022). Consequently, research in this domain should embrace a broader value co-creation perspective, engaging multiple stakeholders and considering social benefits alongside economic factors when evaluating hydrogen system investments, rather than solely relying on traditional cost–benefit analyses (van der Spek et al. 2022). Furthermore, investigations into the complex interactions between actors, technologies, and institutions are crucial for comprehending the net-zero transition and the integration of hydrogen within it (Andersen and Geels 2023; Köhler et al. 2019).

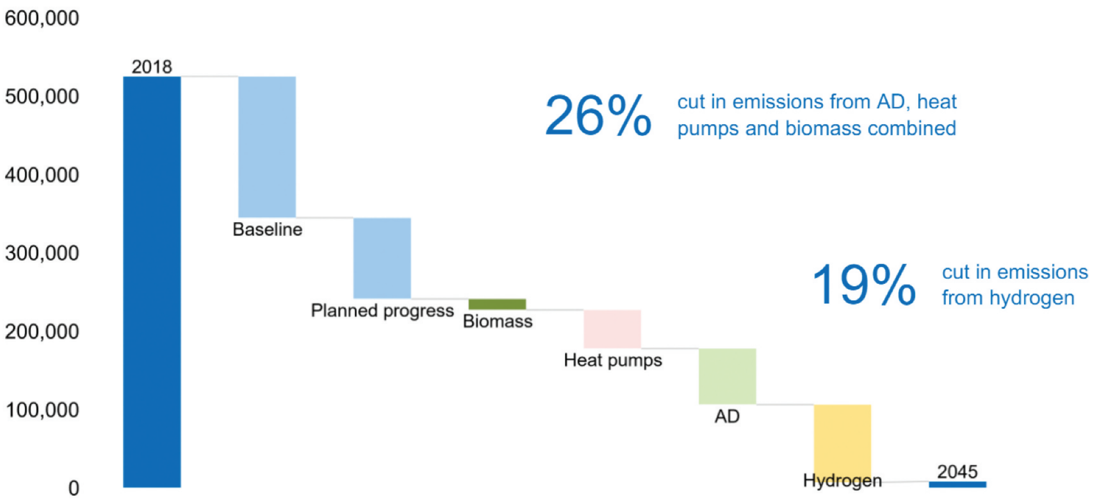

Figure 2. Contributions of different measures to the reduction of emissions of the Scottish whisky industry. Source: Raphael (2020)

Given the multifaceted challenges and the necessity for collaborative solutions in achieving net-zero emissions with hydrogen, a broader theoretical lens is required. Service-dominant logic (SDL) provides such a framework, suggesting that economic exchange is fundamentally rooted in service provision, rather than merely balancing production and demand (Ralf et al. 2017; Vargo and Lusch 2008, 2016). Furthermore, SDL emphasizes the co-creation of value among multiple actors (Lusch and Nambisan 2015; Ralf et al. 2017). This approach not only reinterprets marketing and other business activities but also aligns them with resource integration (Lusch and Vargo 2014) and environmental sustainability (Vargo and Lusch 2017). From this service-oriented perspective, the present study aims to investigate how the Scottish whiskey industry can achieve its net-zero emission target by transitioning to hydrogen.

The following research objectives help to achieve the research aim:

1. Understanding challenges facing the hard-to-treat food and agriculture sector, their needs for support in the transition to meet zero-emission, by a case of whiskey industry.
2. Exploring the opportunities for hydrogen-empowered net-zero emission energy system to be implemented in the hard-to-treat sector, and
3. Eventually contributing to the development of a regional transition pathway to net-zero emission.

As a part of the project, this paper, based on a pilot study in Scottish whiskey industry, will present empirical evidence for the potential of hydrogen to realize net-zero emission.

The next sections, we review the extant literature in service dominant logic and research on the pathways to net-zero emission. The research methodology and details of study design is justified and provided. The results are then presented and discussed. The paper concludes through summarizing the key findings, identifying the limitations and suggesting future studies.

## 2. Materials and methods

### *2.1. Literature review*

The evolution and theoretical development of Service-Dominant Logic (SDL) can be seen as a continuum. Originating in the field of marketing in the 1980s, it has now emerged as a general theory of the market and garnered significant scholarly attention globally in recent years (Rust and Huang 2014; Vargo and Lusch 2016). In contrast, the resource-based Good-Dominant Logic (GDL) prioritizes the optimization of internal and external resources (Mele et al. 2014). However, such perspectives have been criticized for treating services as mere outputs of products, technology, or other tangible/intangible resources (Lusch and Vargo 2014; Mele et al. 2014).

SDL, on the other hand, transcends the traditional boundaries between products and services, physical and intangible resources, and providers and users. It emphasizes the co-creation of value, resource integration, and engagement (Lusch and Nambisan 2015; Mele et al. 2014; Vargo and Lusch 2016). Specifically, SDL highlights the importance of operant resources, such as customer co-produced knowledge (Blazevic and Lievens 2018; Gao and Yu 2023; Vargo and Lusch 2016), cooperation and management (Hsu, Hsieh, and Yuan 2013), values, brands, and service systems (Aal et al. 2016), and institutional arrangements (Vargo and Lusch 2016) for value co-creation. This contrasts with the role played by operand resources, i.e., relatively static natural resources (Vargo and Lusch 2016).

SDL conceptualizes service as a dynamic process involving specialized competencies, such as knowledge and skills, applied through actions, processes, and performance for the benefit of another entity or oneself (Vargo and Lusch 2004). Thus, from an SDL perspective, value is co-created collaboratively as an outcome of service exchange (Edvardsson, Tronvoll, and Mi Dahlgaard Park 2013; Gao and Yu 2023; Vargo and Lusch 2016). The key to value co-creation lies not in the mere provision and utilization of natural resources but in the continuous interplay of resource creation and application facilitated through reciprocal exchange, differential access, and integration.

This notion of value co-creation and service exchange underpins the present study's focus on service as a critical factor in the adoption of hydrogen for achieving zero emissions, rather than merely viewing hydrogen as a natural resource.

While research has often contextualized SDL within the service sector (Aal et al. 2016; Hsu, Hsieh, and Yuan 2013), recent service research has highlighted the need for empirical studies on how tangible and intangible resources can be leveraged (Aal et al. 2016). This includes exploring the implications for the manufacturing sector (Gao and Yu 2023; Rubalcaba, Gallego, and Den Hertog 2010) and how SDL can be utilized to promote environmental sustainability (Lusch and Vargo 2016; Matthies et al. 2016). This paper addresses these gaps by focusing on traditional, non-technologically driven SMEs within a hard-to-treat sector, specifically the whiskey industry. It seeks to answer the question:

How does the traditional whiskey industry shift to hydrogen as an energy source to achieve net-zero emissions?

The escalating recognition of climate change as a paramount global challenge for current and future generations has fostered a consensus on the necessity of phasing out fossil fuels in industrial processes and achieving net-zero emissions (Adams et al. 2020; Bithas and Kalimeris 2018; Frodyma, Papież, and Śmiech 2020; Hertwich et al. 2019; Shah, Quaid Ali Shah, and Tahir 2022). Ambitious targets to curb greenhouse gas emissions and mitigate the global temperature rise to 2°C have been established by international bodies and national governments (Bistline 2021). These targets are subsequently disseminated to regional authorities, corporations, and other stakeholders (Bistline 2021). Notably, the UK government has committed to achieving net-zero emissions by 2050, while the Scottish government has set an even more ambitious goal of 2045 (UG n.d.).

Decarbonizing energy systems is crucial for achieving net-zero emissions. However, reducing emissions from hard-to-treat sectors, particularly food and agriculture, presents a significant challenge (Fankhauser et al. 2022; Pye et al. 2021). Consequently, achieving net-zero emissions in this sector has become a focal point of current research (Fankhauser et al. 2022). The Scottish whiskey industry, a major contributor to UK exports and a substantial energy consumer, aims to achieve net-zero emissions by 2040 (Angleitner et al. 2021; Früh et al. 2021; Raphael 2020; Scottish Government 2021). Yet, transitioning to net-zero while maintaining economic growth is complex (Bataille 2020; Davis et al. 2018).

To aid policymakers, companies, and stakeholders in developing plans, identifying consensus, and clarifying challenges, various energy system models have been proposed and implemented (Bistline 2021). Pathways to net-zero emission systems vary (Bistline 2021). Integrated Assessment Models (IAMs) adopt a global, integrated perspective on interactions and technological changes, linking net-zero emissions to macro factors such as energy, land, climate, and the economy. Conversely, other models concentrate on technological, regional, sectoral, and temporal solutions for energy and non-energy challenges in sectors like agriculture, forestry, and land use (Bataille 2020; Bistline 2021). Despite the advantages of IAMs in analyzing climate mitigation, the latter approach, adopted in this research, is increasingly utilized to study net-zero systems at regional and sectoral levels (Bataille 2020; Bistline and Blanford 2021; Davis et al. 2018; Waisman et al. 2019). Furthermore, developing a net-zero energy system necessitates novel technological solutions targeting hard-to-treat sectors like food and agriculture (Davis et al. 2018; Pye et al. 2021).

Several prominent trends emerge from net-zero scenarios, including widespread electrification, decarbonizing electricity generation, energy efficiency improvements, fossil fuel reduction and substitution, carbon capture and storage, and behavioral adjustments (Andersen and Geels 2023; IEA 2021; Markard and Rosenbloom 2022; Krishnan et al. 2022). Developing net-zero emissions energy systems, especially ensuring reliable electricity, is considered essential (Axelson et al. 2018; Bataille 2020; Bataille et al. 2016; Davis et al. 2018; van Vuuren et al. 2017). Research is also needed to understand the impact of emerging technologies like long-duration energy storage (Dowling et al. 2020) and renewable power generation fuels (Cole, Frazier, and Augustine 2021) on net-zero energy systems (Bistline 2021).

Davis et al. (2018) emphasized that successful net-zero energy systems require abundant, low-cost, emission-free electricity and mechanisms for rapidly and affordably balancing fluctuating supply and demand, for which hydrogen is a promising solution. Furthermore, hydrogen is recognized as a crucial and viable green alternative to fossil fuels (Bataille 2020; Davis et al. 2018; IEA 2019a). Its potential role in achieving net-zero emissions is evident in the whiskey industry, where it could account for 19% of emission reductions, surpassing other technologies (Raphael 2020). Existing research indicates that hydrogen can reduce both material footprint and emissions (Bataille 2020; Bistline 2021; Davis et al. 2018; Nemet et al. 2018; Sofuoğlu and Kirikkaleli 2023).

Davis et al. (2018) identified two research streams in this area:

(1) focusing on technologies and approaches to decarbonize hard-to-treat energy services, and
(2) on system integration for reliable and cost-effective service provision.

Consequently, there is a call for research on innovative solutions, particularly involving hydrogen and related services (Bataille 2020; Bistline 2021; Davis et al. 2018; Victoria et al. 2021). Studies examining multi-system interactions between actors, technologies, and institutions are valuable for understanding the net-zero transition (Andersen and Geels 2023; Köhler et al. 2019). Locally tailored hybrid solutions, sensitive to specific policies and stakeholders, are considered more effective than generalized approaches for achieving net-zero emissions (Bataille 2020). This service-perspective research aims to address this call with a case study of a Scottish whiskey distillery that has fully transitioned to a hydrogen energy system.

## 2.2. Research methods

### 2.2.1. Empirical setting and case selection

An interpretivist case study was deemed the most suitable methodology for this research for several reasons. First, an exploratory qualitative case study facilitates understanding the what, why, and how of research questions (Creswell and David Creswell 2018), particularly regarding the opportunities, challenges, and feasibility of adopting hydrogen systems as a regional solution for achieving net-zero emissions. Second, case studies allow researchers to deeply understand a multifaceted and evolving context (Yin 2018), which is crucial given the nascent and uncertain nature of hydrogen's role in energy transition (Ricardo Confidential 2020). This study thus employs a case study approach to clarify experiences and inform decision-making regarding decarbonization and net-zero emissions through hydrogen adoption. Third, case study research enables the use of multiple data sources, including interviews, field observations, and documents, enriching understanding through diverse perspectives (Stuart et al. 2009).

Purposeful sampling was employed, aligning with the limited availability of participants possessing in-depth knowledge of this specific context (Suri 2011). Due to the complex nature of the research topic, both the case organization and interviewees were required to have extensive experience in Scottish whiskey industry, relevant policies, and hydrogen production and supply. Consequently, participants were recruited from a Scottish whiskey distillery, a hydrogen solutions provider, and a non-governmental professional body, initially contacted through an author's personal network. A cover letter outlined the study's purpose and assured participant privacy.

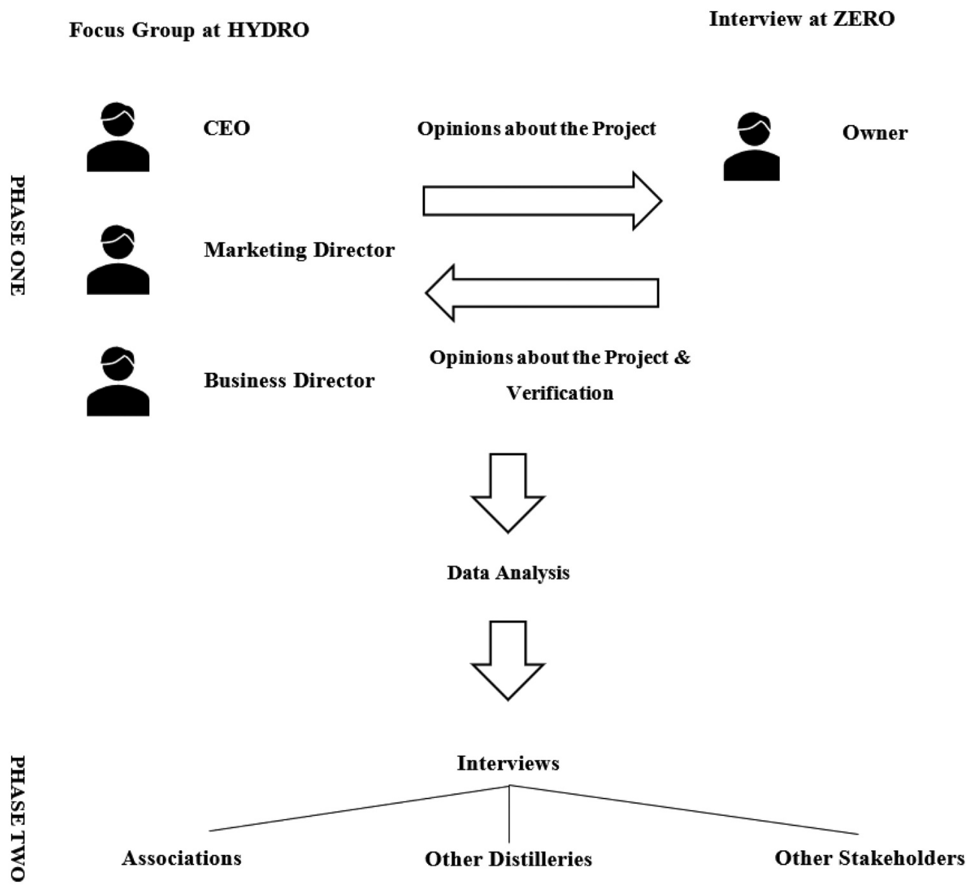

**Figure 3.** Design of the interviews.

Primary qualitative data collection involved eight semi-structured interviews conducted in two phases, as shown in Figure 3, from May to June 2023 and from September to October 2023. Data saturation was reached when no new information emerged (Etikan 2017). The first phase investigated how the hydrogen solutions company (HYDRO) facilitated hydrogen adoption for energy and storage at the whiskey distillery (ZERO) to achieve zero emissions, interviewing HYDRO's CEO, business director, and marketing director. Topics included their views on the research, advantages and disadvantages of hydrogen for the whiskey industry, and challenges and potential solutions. ZERO's owner was then interviewed to verify the collected information. The second phase, through the non-governmental professional body (NGO), explored how other Scottish distilleries approached carbon neutrality, including their reasons for adopting or not adopting hydrogen. Interviews lasted 75–95 min, aligning with reasonable executive interview durations (Malone 2013). Secondary data was gathered from internal documents, marketing reports, and news articles.

Qualitative data analysis utilized thematic analysis to interpret complex data and identify common themes (Gupta and Levenburg 2010). Braun and Clarke's six-step approach (Braun and Clarke 2013) guided this analysis, with emerging codes and themes presented in Tables 1, 2 and 3. The study's validity was enhanced through multiple researchers, multiple interviewees within organizations, and secondary data (Paula, Smith, and Lerman 2021). This triangulation of information strengthened validity and reliability while minimizing subjective bias (Leech and Onwuegbuzie 2007).

Due to data collection from multiple participants, researchers used labels to identify cases before integrating the data (Table 1). The names of individuals and organizations have been changed to avoid identification.

### *2.2.2. Case profile*

This research is contextualized in a project undertaken by HYDRO, a hydrogen solutions provider, for ZERO, a farm-based distillery in Scotland. The project aimed to reinforce ZERO's commitment to producing premium alcoholic beverages while minimizing waste and environmental impact.

By installing their hydrogen facilities on-site, HYDRO enabled ZERO to augment their existing clean energy system, which included wind turbines and solar panels. This expansion allows ZERO to use hydrogen for energy and steam generation, facilitating whiskey and other alcoholic products (Figure 4).

## 3. Results and discussions

### *3.1. Motivations and advantages of adopting hydrogen*

The success of HYDRO in re-designing the distillery into net-zero-emission mode provides empirical evidence for how

**Table 1.** Internal motivations for the commitment to net-zero emissions and adoption of hydrogen.

| Internal Motivations for the Commitment to Net-Zero Emissions and Adoption of Hydrogen | Data |
|---|---|
| Personal commitment of the owner and corporation target to minimalization of waste and sustainability | *Interviewee A 3: (Our) ultimate aim is to produce the best single malt in the world, was* ***to have complete traceability and also minimise any waste and be sustainable as possible which was relatively new in 2013.***<br>*Interviewee C 5: The challenge is being able to get our customers to think a bit differently to be able to put their preconceptions to one side and say look, let us paint a picture for you and then see where we go from there.* ***And that’s where we’ll come onto this later that the distillery (ZERO) has thought differently.*** |
| Corporate strategy to target at a niche market | *Interviewee A 10: . . . it sets a perfect example of what a really small company like us can do. Generally, in the Scotch Whisky Industry the companies are massive . . .* ***They’re making billions a year. They haven’t done it. We who are privately owned, very small are actually showcasing an example of how you can actually do something.*** *So, I mean that for us is really important.* |
| Brand image as being the market leader in sustainability | *Interviewee A 10:* ***I think we will be the first green hydrogen distillery in the world.***<br>*Interviewee A 33: . . .* ***We will set standard and be the first one.*** *So if anyone’s looking at what they’re going to do, there’s no one else to look at the moment. So I think there’s that advantage.* |
| Obtaining competitive advantage and “green credential” | *Interviewee A 12: . . .* ***The fact that we have such a low carbon footprint and are leading the way in sustainability gives us sort of competitive advantage with our spirits.***<br>*Interviewee A 14:* ***We set out to do it (sustainability) for all the right reasons, . . . that we are ahead of the game.*** *And now the advantage we have is because we’ve been doing this for so many years, because we’re farm based, because we grow everything.* ***The larger corporations who are looking at this novel lot more, will look at us where years before they would not have. And they’re looking at us because of our sustainable credentials.***<br>*Interviewee A 36: I think that if Scotland adopts a green energy, and they’ve been doing that anyway. But I* ***think if we become a leader in green hydrogen as well . . . you (we) are competitive in terms of that box and particularly the higher the premium levels****, price is not what drives that it, it’s your story, it’s your credentials and I think that’s where and Scotland’s a small nation, so we have a problem with Labour. So I think aiming at that premium market.* |

businesses from hard-to-treat sector can achieve zero-emission target by adopting hydrogen. The interviews found that:

(1) ZERO has a strong commitment to net-zero emission and sustainability (Interviewee A3, Interviewee A14).

    Interviewee A3: (Our) ultimate aim is to produce the best single malt in the world, and to have complete traceability and also minimize any waste and be sustainable as possible which was relatively new in 2013.

(2) This commitment arises from both internal and external factors (Table 2). Internal motivations encompass the owner’s personal dedication to waste reduction (Interviewee A3, Interviewee C5), a corporate strategy focused on a niche market (Interviewee A10), a brand image as a leader in decarbonization (Interviewee A10, Interviewee A33), and gaining competitive advantages like “green credentials” (Interviewee A12, Interviewee A13, Interviewee A36). External motivations (Table 3) include the ongoing energy crisis (Interviewee A14, Interviewee B7), the need to align with market trends (Interviewee A11), and the technical feasibility of hydrogen adoption (Interviewee A7, Interviewee A9, Interviewee B15).

This suggests that, aligning with the arguments of Geels, Berkhout, and Van Vuuren (2016), Li and Pye (2018), McCollum et al. (2020), and Pye et al. (2021), business owners consider not just engineering but also socio-economic factors,

**Table 2.** External motivations for the commitment to net-zero emissions and adoption of hydrogen.

| External Motivations for the Commitment to Net-Zero Emissions and Adoption of Hydrogen | Data |
|---|---|
| The ongoing energy crisis | *Interviewee A 14: In 2013, when we were talking about regenerative farming, about looking after our natural environment, about minimising waste, there weren’t that many people doing that.* ***So I think the good thing about doing something like this, when the world is kind of waking up to the challenge of global warming, that we are ahead of the game.***<br>*Interviewee C 7: We haven’t had to think differently for a long, long time. Even within our generations everything’s been very stable and static. What’s happened with the Ukraine war is, we’ve realised that, particularly in Europe, when you switch off that gas pipe that all of a sudden, we do not have the energy that we need to heat our homes.* |
| Need for meeting the market trend | *Interviewee A 11:* ***And the opportunity then becomes and particularly with social media and everything more and more people are aware of what we’re doing here.*** |
| Technical probability | *Interviewee A 7: I think the main thing (is that) there is a green hydrogen. So it has to be green.* ***Actually, to find someone that’s producing green hydrogen is extremely difficult, because it just doesn’t really happen.***<br>*Interviewee A 9: The reason instead of batteries is there is not the capability in batteries to power either the steam or a kind which are big agricultural implements.* ***The size and weight of the battery at the moment is way too much. So for us this (hydrogen) looked like the perfect solution.***<br>*Interviewee B 15: There are a number of distilleries that are relatively close to each other in various parts of Scotland. So I said, we can help you sort this out because actually there’s a cluster of you together. So we can provide you with sort of the electricity and hydrogen and whatever what you need. . . And you could work together to do this. They are specialised in making whisky and then good whisky. And that’s their process.* ***So what they need is an energy company to come up with that solution. So that’s an opportunity for us to be an energy (solution provider).*** |

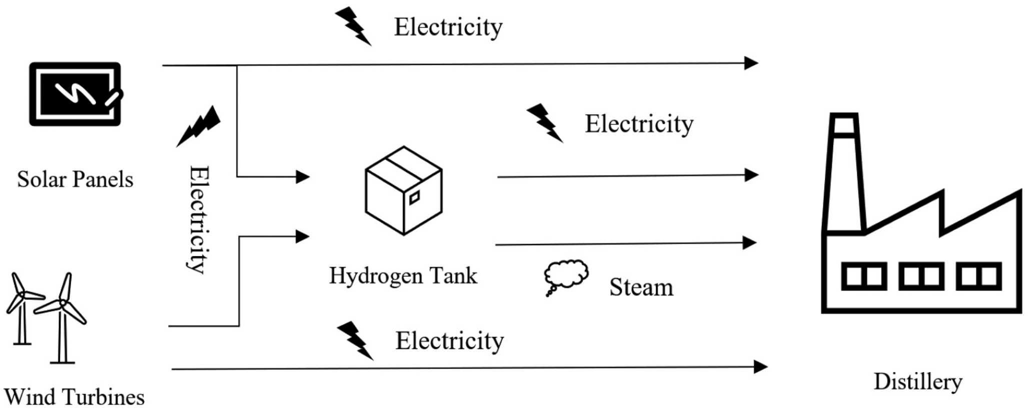

**Figure 4.** The hydrogen system in ZERO.

**Table 3.** Information and codes of participant.

| Organisations | Roles of Participants | Nickname | Codes |
|---|---|---|---|
| ZERO | Owner | Tom | Interviewee A |
| HYDRO | CEO | Brian | Interviewee B |
| | Director of Business | Chris | Interviewee C |

particularly disruptive emergence, when contemplating the shift to hydrogen. Additionally, as a new SME, ZERO demonstrates a preference for partnering with businesses like HYDRO for energy solutions. The key motivations for this choice include efficiency (Interviewee A31), HYDRO's connection to research institutions (Interviewee A30), and most importantly, their availability (Interviewee A30) (Table 4).

The case highlights the distinct advantages of hydrogen for SMEs, particularly those in traditional manufacturing sectors located in remote areas not serviced by large energy providers. These advantages encompass cost, energy security, flexibility, and reliability. This finding supports van der Spek's et al. (2022) conclusion that electrolysis-based hydrogen, in contrast to large-scale fossil-based hydrogen production, is better suited to smaller installations and simpler infrastructure. Hydrogen systems can unlock the potential of businesses like ZERO to contribute to net-zero emissions, not merely as an energy source or storage method, but crucially as a solution to their specific challenges (Interviewee B1, Interviewee B2, Interviewee B3) and a means to achieve energy independence (Interviewee C1, Interviewee B6), security (Interviewee C1, Interviewee C4, Interviewee B7), flexibility (Interviewee C2), efficiency (Interviewee C1, Interviewee B6), and decarbonization (Interviewee C1).

> Interviewee B1: I think we don't regard hydrogen as hydrogen. **We regard it as a way of solving problems**.
>
> Interviewee B2: One thing that's very annoying is saying how much is a kilo of hydrogen worth. Very annoying. **Because no one wants hydrogen . . . they want as a solution**.
>
> Interviewee B3: **It is a method of solving a problem. It's a way of storing energy and moving it from electricity, renewable electricity, or potentially steam methane reformed natural gas, or biogas**.
>
> Interviewee C1: **We work with customers to find how we can give them energy independence, security. And where possible, a better cost for their energy. That might not always be possible, but the first two and carbon reduction. Ultimately, it's carbon reduction. That's what we try and agent**.
>
> Interviewee C2: **Hydrogen gives you more flexibility than that. . . And storage and transport of energy is something that is probably alien to a lot of people out there, . . . with hydrogen you don't have to have a National Grid system, you can have regionalized energy production and usage**.
>
> Interviewee B6: **So that's got nothing to do with hydrogen specifically, but hydrogen is key to that. That's a way to store energy, but that's all converted to a some fairly like (fertilizer)**.
>
> Interviewee C4: **a number of farmers in a particular area. Maybe we need to expand that out and find what is the best way of doing this**.
>
> Interviewee B7: So **it's security of supply, it's security of cost, it's low carbon potentially if they use their own resources. . . . and it gives them stability, commercial stability, production stability**.

Therefore, hydrogen is a potential source of energy storage for any business that can adopt it, particularly farms and distilleries (Interviewee B3, Interviewee B 5, Interviewee B6, Interviewee C12, Interviewee B15).

**Table 4.** Motivations for adopting hydrogen.

| Motivations for Adopting HYDRO | Data |
|---|---|
| Efficiency | *Interviewee A 31 . . . we always like smaller suppliers, when you're dealing with a big corporates, things are slow. . . . I know how slow you've got to go various things. So it tends to be slower in a big corporate.* |
| Link of HYDRO to research institutes | *Interviewee A 30: . . . And obviously (HYDRO is) based in Scotland and they (HYDRO)'ve got their ties with (Anonymous) University and everything.* |
| Availability | *Interviewee C 30: . . .When we were looking at the scheme and what was available. You then look at who is in each space and who is leaders in space . . . They just they were a natural partner for us to push forward.* |

> Interviewee B3: **hydrogen, as we can see, is particularly suitable for any particular issue**.

> Interviewee B5: **Sectors are most likely to adopt hydrogen as a new energy**.

> Interviewee C12: But ultimately, we can do it from one particular element (which is hydrogen) . . . So, when we come back to the distillery, . . . here's an opportunity for you using hydrogen.

> Interviewee B15: So another conversation I have with them (owners of distilleries), is about there are a number of distilleries that are relatively close to each other in various parts of Scotland . . . **what they need is someone, an energy company to come up with that solution**. So that's an opportunity for us to be an energy (solution provider).

### *3.2. Challenges of shifting to hydrogen system*

Meanwhile, challenges are identified in the pilot study:

Both HYDRO and ZERO identify high cost and lack of investment as the primary obstacles to wider adoption of hydrogen systems. This is attributed to the technology being perceived as expensive and unproven (Interviewee A15, Interviewee B9).

> Interviewee A15: **The largest one (challenge) I would think for anyone is cost. So, at the moment hydrogen is a new technology and all new technologies tend to be expensive, unproven**. So for people to take the risk to go into hydrogen spending a lot of money, I think it's the unproven technology. It's the only real risk I see – cost.

> Interviewee B 9: **Quite often the reaction is, well, it can't be that expensive. I can't afford that**.

HYDRO emphasizes that insufficient support stems from inadequate engagement with users and a failure to consider the issue and its value from an integrated perspective (Interviewee B9).

> Interviewee B9: **They (users) are not engaging with the problem, they are reacting to the price**. So we've developed a system that they can have solar panels on their roof. They generate hydrogen and use it and surplus they put into storage and then when they have a deficiency, they take it from the storage. . .**So hydrogen is providing a solution for them to say we have roof space that is a resource, because we can get sunshine on it and use that sunshine, and we can drive our vehicles all year round on that sunshine**.

Both HYDRO and ZERO express a need for greater support, particularly financial (Interviewee A16, Interviewee A21). They perceive current government and financial institution incentives as taking a generic, price-focused approach that overlooks specific cases like small hydrogen solution providers and their potential value.

Crucially, both entities believe that beyond financial incentives, the creation of a "level playing field" that encourages public and commercial investment is paramount for the transition to net-zero (Interviewee A38, Interviewee B9, Interviewee B10). This aligns with van der Spek et al. (2022), who note that businesses face commercial, political, and financial barriers to hydrogen adoption, requiring government intervention with a "coherent strategic rationale for investment" and collaborative support from multiple stakeholders across the supply network and society.

Regarding hydrogen adoption, HYDRO stresses the importance of a broader perspective that recognizes its potential value beyond mere cost (Interviewee B9, Interviewee B10). This resonates with van der Spek et al. (2022) and Stern (2019), who advocate for a model that considers societal value and delivers integrated outcomes for multiple stakeholders in implementing hydrogen systems. It also addresses Fehrer, Kemper, and Baker's (2024) call for a service-oriented approach to circular economy studies, encompassing a systemic view and multiple actors engaged in value co-creation.

> Interviewee A16: I think there's always challenges. There's always challenges with putting anything that's really new . . . **And what should have happened is the UK government and the funders should have increased funding slightly**. Because everyone knows the challenges of any kind of cost and the government is aware of this. **They should have looked upon as a special case and allocated more money toward it**.

> Interviewee A21: The advantage the smaller ones potentially have is they tend to be newer. They tend to be smaller. So actually, it doesn't take so much to change.

> Interviewee A38: I think it (shifting to hydrogen) is hard. **I think what the government then must do is to put in the playing field where it makes. . .. And whatever that investment structure is to encourage private companies to enter that . . . (the government needs) to try and drive companies in the bigger investors and companies to zero-emissions. And then and you see that everywhere when you get clusters as well, whether the technology and Seattle or . . . Once you get that cluster effect, you get more innovation and more drive. And I think that's what the government can try to do**.

> Interviewee B9: **Quite often the reaction is, well, it can't be that expensive. I can't afford that. Someone's got the government's got to do something about reducing the cost**.

> Interviewee B10: **On the policy, there is a document out at the moment for consultancy around how government is going to subsidize hydrogen production. That comes back to a cost per kilo of hydrogen, which comes back to they're trying to solve the wrong problem. Because people don't want hydrogen. They want (solutions)**.

An additional barrier hindering other distilleries from embracing hydrogen, as noted by van der Spek et al. (2022), is its novelty as an unproven technology, coupled with associated risks (Interviewee A24, Interviewee A28). These risks have been identified in other sectors adopting or exploring hydrogen, as evidenced by Andreas, Goldthorpe, and Avignon (2020) and Goldthorpe and Avignon (2020). Addressing these risks necessitates support and collaboration with research institutions, including universities (Interviewee A25, Interviewee A26).

> Interviewer: In meanwhile, you just mentioned that you have lots of stuff with strong technical knowledge about this kind of stuff. Is this a kind of barrier for others they haven't done it yet?

> Interviewee A24: Yes, 400%. Yeah.

> Interviewee A28: I think we've mentioned COVID already in supply issues which is huge. I think when it's new and innovative, the challenges there are looking at things where there's no real

> blueprint for doing it. I know discussions took way longer than they should because they couldn't get their head round it a waste product of oxygen and water, wasn't dangerous . . . **when you've got new technologies, there's always elements you're not 100% sure of. So I think that's probably the main aspects**.

> Interviewee A25: We embrace new technologies. We do a lot of pilot schemes. Not everything's going to work. And that's where many ways universities and government funding come in, because we wouldn't have done the intercropping project if we hadn't been paid for it, because we just can't afford to do that. We'd be out of business.

> Interviewee A26: **I think fundamentally it is research institutions and universities backed by government and funding, putting the right place, that is one of the wheels to make it work**.

Apart from government and research institutes, commercial investments are identified and stressed by both HYDRO and ZERO as critical supports for distilleries to adopt hydrogen (Interviewee A27, Interviewee C10).

> Interviewee A27: **The next thing is unquestionably is commercial business**. . . They are the people that should be stepping in and doing partnerships and working with people like ourselves.

> Interviewee C10: **And those areas are going to be dependent on investment coming in**. because particularly in the UK, when it comes to energy, we've privatized everything. **Well, that means we need private investment. Government handing out subsidies is not going to help**. It's only a short-term gap and ultimately the taxpayer pays for it. That's not the way this will need to change. **We need government policy to allow people to come in and invest**.

Extant literature calls for research on sector-specific and regional pathways to hydrogen adoption and net-zero emissions (Bataille 2020; Bistline and Blanford 2021; Davis et al. 2018; Waisman et al. 2019). The interview findings indicate insufficient awareness among government, investors, users, and other key stakeholders about green hydrogen's potential not just as an energy source, but also as a solution to specific problems (Interviewee C5, Interviewee C6, Interviewee B9, Interviewee C10, Interviewee B12).

Local community and business perspectives, rather than a solely UK-centric view, are necessary for recognizing hydrogen as a solution to local issues like energy storage, maximizing renewable energy use, and gaining competitive advantages, rather than solely as an energy source (Interviewee C8, Interviewee B9, Interviewee B10). This finding aligns with Goldthorpe and Avignon (2020), whose pan-European research emphasizes the need to differentiate between macro-economic and micro-economic models for hydrogen adoption.

> Interviewee C5: **The challenge is being able to get our customers to think a bit differently to be able to put their preconceptions to one side and say look, let us paint a picture for you and then see where we go from there. And that's where we'll come onto this later that the distillery has thought differently.**

> Interviewee C6: **We have huge reliance on one source, and we can't have that. We have got to think differently, and I think it's also made the rest of the world realize that actually we need to accelerate**. Obviously, decarbonizing is the most important thing. We need to protect the environment. **But step by step, that ability to be able to produce locally, what you need is important**.

> Interviewee B9: Quite often the reaction is, well, it can't be that expensive. I can't afford that. Someone's got the government's got to do something about reducing the cost. **So they're not engaging with the problem, they are reacting to the price . . . Hydrogen is providing a solution for them who have roof space that is a resource**, because we can get sunshine on it and use that sunshine . . . even when it's dark. Because we've stored overnight and over the year, so it's short term and long term . . . And it would be sort of they would potentially need less this capital outlay. . .

> Interviewee B10: This is government doing it (incentivization for small users). So this collection of farmers that want to produce their own ammonia . . . **And so they are completely missing the energy problem. And they're turning into a hydrogen problem or solution or a hydrogen problem, in fact. So actually, you will then get loads of people out there saying: "excellent, I can produce all this hydrogen and I'll get paid to do it. Who's going to use it?" So you then created a problem of who's going to use it? It's not necessarily the right answer for solving our problems because they're looking at it from a UK perspective. They're not looking at it from an individual community perspective**.

> Interviewee B12: They (policy makers) need to talk to us to understand policy and policies, . . . I mean so we have views on hydrogen. But we also have views on the whole energy side of things as far as sort of local production, centralized production . . . **We're using existing, proven technology in an innovative way**.

Finally, there's a perception that the market is not yet ready for distilleries to fully embrace green practices (Interviewee A29). Demand for net-zero products primarily comes from business clients like retailers, rather than end-consumers (Interviewee A29, Interviewee B14). This necessitates an integrated perspective encompassing the entire supply chain for a successful transition to net-zero emissions or hydrogen adoption.

The literature acknowledges that the market for hydrogen requires tailoring, emphasizing that despite substantial demand, it needs to be actively created and matched to diverse supply options (Bødal et al. 2020; Lewis 2020; van Cappellen, Croezen, and Rooijers 2018; van der Spek et al. 2022).

> Interviewee A29: **It (the green market) is not mature enough, but there is a growing amongst the big corporates and the big buyers, there's a growing need for them to be looking at sustainable supply**.

> Interviewee B14: **So whiskey producers are . . . I don't know why, but their customers which are not you and me drinking whiskey, they are the wholesalers, are demanding zero-carbon whiskey**.

## 4. Conclusions

### 4.1. *Theoretical implications*

This research, based on a Scottish whiskey distillery case study, examines how a business in the "hard-to-treat" sector achieves net-zero emissions through a transition to a hydrogen system. Interviews with managers from the distillery (ZERO) and the hydrogen system provider (HYDRO) aimed to fulfill three research objectives:

(1) Understanding the challenges faced by the hard-to-treat food and agriculture sector and their support needs in the transition to zero-emission.

(2) Exploring opportunities for implementing hydrogen-powered net-zero emission energy systems in the hard-to-treat sector.
(3) Contributing to the development of a regional transition pathway to net-zero emission.

The research findings align with the conclusions of Davis et al. (2018) and Pye et al. (2021), emphasizing the challenges inherent in the transition of hard-to-treat sector businesses and the necessity of novel technological solutions. The ZERO case demonstrates the potential for businesses to achieve the three pathways to net-zero emissions identified by Bataille (2020): material efficiency, production decarbonization, and circularity. Despite its significant advantages, hydrogen adoption faces barriers that require overcoming through robust political and financial support, collaborative infrastructure development, market design, and business model innovation, as highlighted by van der Spek et al. (2022).

The farm-based distillery ZERO utilizes its agricultural outputs for alcoholic beverage production and generates power through wind and solar energy. However, their traditional steam production for distillation relied on fossil fuels. By adopting a hydrogen system, they have achieved a complete energy cycle and clean production. Excess electricity generated from wind turbines and solar panels is stored as hydrogen, which can be used for steam generation or electricity production when wind and sunlight are scarce.

Therefore, in this case, hydrogen serves not merely as an energy source for ZERO, but as a solution for decarbonizing production and enabling the circular economy within which the distillery operates. This finding aligns with calls for modeling that extends beyond net-zero emissions to encompass a broader shift toward a sustainable circular economy, consistent with the UN Sustainable Development Goals (SDGs) (Pye et al. 2021; Waisman et al. 2019).

Furthermore, ZERO's decision to accelerate its net-zero emission efforts and adopt hydrogen due to external factors, notably the ongoing energy crisis and the war in Ukraine, underscores the significant impact of disruptive socio-economic events on the transition to net-zero emissions (McCollum et al. 2020). This highlights the importance of such factors in research (Pye et al. 2021).

This research takes a service perspective. As stressed by Davis et al. (2018): "People do not want energy itself, but rather the services that energy provides and the products that rely on these services." The findings align with Davis et al. (2018), Geels, Berkhout, and Van Vuuren (2016), Li and Pye (2018) and Pye et al. (2021), suggesting that an interdisciplinary scope which consider socio-political issues, engagement with multiple stakeholders, and a service perspective are needed to evaluate the potential of hydrogen system and its provider for empowering businesses. Particularly for SMEs from remote areas, not only to achieve their net-zero emission targets but also to implement corporate strategy and premium products. From the perspective of the distillery, the hydrogen energy system as well as relevant services is not only a source of clean energy, but also a part of their brand image, premium quality/services, and competitive advantage in stability, efficiency, and flexibility. This aligns with Åhman, Nilsson, and Johansson (2017), Bataille (2020) and Pye et al. (2021) who argue that transition to decarbonized production requires broader scope of measurement that includes the cooperation with multiple actors including government, firms, and institutions. Investors, policymakers, and researchers should consider both the role of hydrogen as a fuel for carbon emission reduction and the accompanying services that enable users to achieve net-zero targets without compromising commercial interests. This case reinforces the conclusions of Bistline (2021) and van der Spek et al. (2022), highlighting the need for funding and input from policymakers and industry in research areas that benefit from collaboration. Both participant companies strongly believe the support of government is inadequate and, more importantly, too generic to help the local SMEs. This finding aligns with the existing literature that call for granular modeling at subnational and sectoral levels that take overlapping policies and incentives into consideration and address market barriers e.g. standards, tax credits, etc. (Bistline 2021; van der Spek et al. 2022).

Furthermore, existing research employing Service-Dominant Logic (SDL) calls for empirical evidence from the manufacturing sector on how tangible and intangible resources are leveraged to enhance environmental sustainability (Aal et al. 2016; Gao and Yu 2023, Lusch and Vargo 2014; Matthies et al. 2016; Rubalcaba, Gallego, and Den Hertog 2010). This research underscores that service involving multiple actors is crucial for adopting hydrogen as a local solution, empowering a circular economy, and ultimately achieving net-zero emissions.

In this context, service is not simply an output of the hydrogen system and its installation, but, as highlighted by Gao and Yu (2023), Lusch and Vargo (2016), and Mele et al. (2014), the integration of resources like solar and wind energy, the farm, and technology. This integration requires value co-creation with multiple stakeholders. Hydrogen should not be viewed as a static, operand natural resource. Its potential for empowering the circular economy and realizing net-zero emissions is unlocked when considered an operant resource, alongside co-produced knowledge, cooperation, management, values, brands, service systems, and institutional arrangements for value co-creation (Aal et al. 2016; Blazevic and Lievens 2018; Gao and Yu 2023; Hsu, Hsieh, and Yuan 2013; Vargo and Lusch 2016).

Therefore, SDL, which recognizes the ongoing interplay of resource creation and application through reciprocal exchange and differential access and integration (Gao and Yu 2023), is essential for evaluating hydrogen's contribution to net-zero emissions.

Moreover, the ZERO case study extends beyond the mere adoption of a hydrogen system for net-zero emissions. It illustrates how this technology empowers a business in a hard-to-treat sector to optimize its circular economy. This research, therefore, responds to Fehrer, Kemper, and Baker's (2024) call for Service-Dominant Logic (SDL) to be embraced as a fresh perspective and methodology that illuminates collaborative value co-creation.

The findings support the notion that goods-dominant logic, which upholds a narrative of economic exchange and hinders the development of circular economy narratives (Vink et al.

2021), should be superseded by SDL. This shift entails a focus on collaborative action involving path interdependency, engagement in value proposition negotiations, and a pursuit of mutually beneficial outcomes (Fehrer, Kemper, and Baker 2024).

Finally, the ZERO case study, along with feedback from HYDRO, provides empirical evidence and a representation of a new fuel pathway centered on hydrogen systems (Pye et al. 2021). This suggests that focusing solely on hydrogen as a fuel might obscure its potential as a solution to specific problems, such as the need for efficient and clean steam production in the case of ZERO.

As demonstrated by ZERO, hydrogen systems offer competitive advantages over other options in terms of efficiency, stability, and flexibility for supporting diverse projects and businesses requiring energy solutions (van der Spek et al. 2022). These systems enable and empower traditional SMEs to achieve net-zero emission targets while realizing energy independence, security, and commercial interests.

Therefore, transitioning to hydrogen systems presents a potential pathway to achieve decarbonization without sacrificing commercial interests, which is crucial for sustainable solutions toward net-zero emissions (Davis et al. 2018; van der Spek et al. 2022). These problems are often locally specific and not directly related to energy provision or net-zero emissions.

In essence, hydrogen's potential for enabling businesses to decouple growth from decarbonization (Sofuoğlu and Kirikkaleli 2023) and align near-term actions with long-term net-zero goals (Pye et al. 2021) needs to be acknowledged and further explored.

Specifically, this research highlights the advantages of hydrogen generated by electrolysis, particularly using wind and solar power, over fossil-based "blue hydrogen." These advantages include cost, security, flexibility, and the ability to empower SMEs in hard-to-treat sectors like food and agriculture to transition to net-zero emissions. This finding aligns with van der Spek et al. (2022), who notes that oil-based hydrogen systems are more prevalent in large-scale projects, while electrolysis-based systems are favored for smaller projects.

Furthermore, ZERO's clear preference for partnering with HYDRO, a smaller hydrogen solution provider, provides empirical evidence supporting van der Spek et al. (2022) conclusion that electrolysis-based hydrogen, due to its positive image as a low-carbon solution, will gain market share and potentially replace fossil-based hydrogen as the primary sustainable decarbonization solution.

### 4.2. *Practical implications*

The findings of this research offer practical implications for businesses, policymakers, and other key stakeholders to better understand the potential of hydrogen systems for decarbonization and develop regional or community pathways to net-zero emissions.

Specifically, government support and plans for zero-emission are often inadequate and too generic to address the specific challenges faced in different regions and communities. Businesses rely heavily on commercial support, which requires policy endorsement and guidance. Therefore, both national and regional governments need to create conditions that attract commercial investment in hydrogen systems. These conditions include not only financial incentives but also research and accreditation initiatives that engage multiple stakeholders.

Furthermore, pathways to zero-emissions should be developed to address regional and community problems beyond energy-focused issues. Hydrogen can play a crucial role in these solutions. This case study suggests that the current government policy, which primarily focuses on decarbonization, may overlook opportunities to support businesses and communities in achieving net-zero emissions indirectly.

Finally, a shift in mind-set and perspective is needed regarding hydrogen as a tool for empowering businesses to achieve zero-emissions. The potential of hydrogen systems should be viewed through a service lens, recognizing them as solutions to specific problems rather than just energy sources. Governments and investors need to evaluate hydrogen systems based on their value creation, such as increasing business and community flexibility, energy security, independence, and sustainability, rather than solely focusing on their price.

### 4.3. *Limitations and future research*

This paper presents findings and conclusions from a pilot study exploring how traditional SMEs can achieve net-zero emissions by adopting hydrogen systems. While the case study findings require validation through perspectives from other stakeholders within the sector, such as additional whiskey distilleries and associations, the insights gleaned here will inform a regional pathway to net-zero emissions. This pilot study paves the way for the second research stage, commencing in September 2023, which will investigate other distilleries and textile manufacturers who have not yet achieved net-zero emissions, or those who have done so through means other than hydrogen adoption. The next stage aims to create a nationwide case study based on the Scottish whiskey industry, ultimately contributing to the development of regional and sectoral pathways for decarbonization (Waisman et al. 2019).

Furthermore, future research should incorporate quantitative data collection to examine the attitudes and opinions of businesses in the region regarding net-zero emissions and different approaches, including their advantages and disadvantages.

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## References

Aal, K., L. Di Pietro, B. Edvardsson, M. Francesca Renzi, and R. Guglielmetti Mugion. 2016. Innovation in service ecosystems: An empirical study of the integration of values, brands, service systems and experience rooms. *Journal of Service Management* 27 (4):619–51. doi: 10.1108/JOSM-02-2015-0044.

Adams, S., F. Adedoyin, E. Olaniran, and F. Victor Bekun. 2020. Energy consumption, economic policy uncertainty and carbon emissions: Causality evidence from resource rich economies. *Economic Analysis and Policy* 68:179–90. doi: 10.1016/j.eap.2020.09.012.

Åhman, M., L. J. Nilsson, and B. Johansson. 2017. Global climate policy and deep decarbonization of energy-intensive industries. *Climate Policy* 17 (5):634–49. doi: 10.1080/14693062.2016.1167009.

Andersen, A. D., and F. W. Geels. 2023. Multi-system dynamics and the speed of net-zero transitions: Identifying causal processes related to technologies, actors, and institutions. *Energy Research & Social Science* 102:103178. doi: 10.1016/j.erss.2023.103178.

Andreas, J., W. Goldthorpe, and L. Avignon. 2020. Deliverable nr. D5.6.1 commercial methodologies for early CO2 cluster development and expansion.

Angleitner, B., J. Kluge, S. Lappöhn, K. Plank, L. Mateeva, and A. Schnabl. 2021. *The economic and ecological footprint of the spirits sector in the EU, the UK*. Norway and Switzerland. Vienna, Austria: IRIHS. https://irihs.ihs.ac.at/id/eprint/5957/.

Antonini, C., K. Treyer, A. Streb, M. van der Spek, C. Bauer, and M. Mazzotti. 2020. Hydrogen production from natural gas and biomethane with carbon capture and storage – a techno-environmental analysis. *Sustainable Energy and Fuels* 4 (6):2967–86. doi: 10.1039/D0SE00222D.

Axelson, M., I. Robson, T. Gilberte Wyns, and A. Gauri. 2018. *Breaking through - industrial low-CO2 technologies on the horizon*. https://www.ies.be/files/Breaking_Through_Industrial_Low-CO2_Technologies_on_the_Horizon_IES_13072018_0.pdf.

Bataille, C. G. F. 2020. Physical and policy pathways to Net-zero emissions industry. *WIREs Climate Change* 12 (1):e633. doi: 10.1002/wcc.684.

Bataille, C., H. Waisman, M. Colombier, L. Segafredo, J. Williams, and F. Jotzo. 2016. The need for national deep decarbonization pathways for effective climate policy. *Climate Policy* 16 (1):S7–26. doi: 10.1080/14693062.2016.1173005.

Bistline, J. E. T. 2021. Roadmaps to Net-zero emissions Systems: Emerging insights and modeling challenges. *Joule* 5 (10):2551–63. doi: 10.1016/j.joule.2021.09.012.

Bistline, J. E. T., and G. J. Blanford. 2021. The role of the power sector in net-zero energy systems. *Energy and Climate Change* 2:10045. doi: 10.1016/j.egycc.2021.100045.

Bithas, K., and P. Kalimeris. 2018. Unmasking decoupling: Redefining the resource intensity of the economy. *Science of Total Environment* 619:338–51. doi: 10.1016/j.scitotenv.2017.11.061.

Blazevic, V., and A. Lievens. 2018. Managing innovation through customer coproduced knowledge in electronic services: An exploratory study. *Journal of the Academy of Marketing Science* 36 (1):138–51. https://link.springer.com/article/10.1007/s11747-007-0064-y.

Bødal, E. F., D. Mallapragada, A. Botterud, and M. Korpås. 2020. Decarbonization synergies from joint planning of electricity and hydrogen production: A Texas case study. *International Journal of Hydrogen Energy* 45 (58):32899–915. doi: 10.1016/j.ijhydene.2020.09.127.

Braun, V., and V. Clarke. 2013. *Successful qualitative research: A practical guide for beginners*. Los Angeles: SAGE.

Cole, W., A. W. Frazier, and C. Augustine. 2021. *Cost projections for utility-scale battery storage: 2021 update. national renewable energy Lab.(nrel)*. Golden, CO: United States. doi: 10.2172/1786976.

Creswell, J. W., and J. David Creswell. 2018. *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, California: Sage publications.

Davis, S., N. S. Lewis, M. Shaner, S. Aggarwal, D. Arent, I. Azevedo, S. M. Benson, T. Bradley, J. Brouwer, Y.-M. Chiang, et al. 2018. Net-zero emissions energy Systems. *Science* 360 (6396). doi: 10.1126/science.aas9793.

Dodds, P. E., I. Staffell, A. D. Hawkes, F. Li, P. Grünewald, W. McDowall, and P. Ekins. 2015. Hydrogen and fuel cell technologies for heating: A review. *International Journal of Hydrogen Energy* 40 (5):2065–83. doi: 10.1016/j.ijhydene.2014.11.059.

Dowling, J. A., K. Z. Rinaldi, T. H. Ruggles, S. J. Davis, M. Yuan, F. Tong, N. S. Lewis, and K. Caldeira. 2020. Role of long-duration energy storage in variable renewable electricity systems. *Joule* 4 (9):1907–28. doi: 10.1016/j.joule.2020.07.007.

EC (European Commission). 2020. *A hydrogen strategy for a climate neutral Europe*. European Commission. https://energy.ec.europa.eu/system/files/2020-07/hydrogen_strategy_0.pdf.

Edvardsson, B., B. Tronvoll, and S. Mi Dahlgaard Park. 2013. A new conceptualization of service innovation grounded in S-D logic and service systems. *International Journal of Quality & Service Sciences* 5 (1):19–31. doi: 10.1108/17566691311316220.

ETC (Energy Transition Commission). 2021. Making clean electrification possible: 30 years to electrify the global economy. *Energy Transition Commission* 25. https://www.energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Power-Report-.pdf.

Etikan, I. 2017. Sampling and sampling methods. *Biometrics & Biostatistics International Journal* 5 (6):00149. doi: 10.15406/bbij.2017.05.00149.

Fankhauser, S., S. M. Smith, M. Allen, K. Axelsson, T. Hale, J. M. K. Cameron Hepburn, J. M. Kendall, R. Khosla, J. Lezaun, E. Mitchell-Larson, et al. 2022. The meaning of net zero and how to get it right. *Nature Climate Change* 12 (1):15–21. doi: 10.1038/s41558-021-01245-w.

Fehrer, J. A., J. A. Kemper, and J. J. Baker. 2024. Shaping circular service ecosystems. *Journal of Service Research* 27 (1):49–68. doi: 10.1177/10946705231188670.

Fraser, I. 2021. Net zero 2040: Scotch Whisky's big green agenda. Whisky Invest Direct. https://www.whiskyinvestdirect.com/whisky-news/green-whisky-091020211.

Frodyma, K., M. Papież, and S. Śmiech. 2020. Decoupling economic growth from fossil fuel ese: Evidence from 141 countries in the 25-year perspective. *Energies* 13 (24):6671. doi: 10.3390/en13246671.

Früh, W.-G., J. Hillis, S. Gataora, and D. Maskell. 2021. Reducing the carbon footprint of whisky production through the use of a battery and heat storage alongside renewable generation. *Renewable Energy and Power Quality Journal* 19 (2021):429–34. doi: 10.24084/repqj19.310.

Gao, B., and K. Yu. 2023. Knowledge exchange in SMEs service innovation with design thinking. *Management Decision* 61 (7):2029–49. doi: 10.1108/MD-06-2022-0795.

Geels, F. W., F. Berkhout, and D. P. Van Vuuren. 2016. Bridging analytical approaches for low-carbon transitions. *Nature climate change* 6 (6):576–83. doi: 10.1038/nclimate2980.

Goldthorpe, W., and L. Avignon. 2020. "A system approach to business models and public-private risk sharing for large scale CCS deployment." *Proceedings of the 15th Greenhouse Gas Control Technologies Conference*, 2021 March 31, 15–18.

Gupta, V., and N. Levenburg. 2010. A thematic analysis of cultural variations in family businesses: The CASE project. *Family Business Review* 23 (2):155–69. doi: 10.1177/089448651002300205.

Hertwich, E. G., S. Ali, L. Ciacci, T. Fishman, N. Heeren, E. Masanet, F. N. Asghari, E. Olivetti, S. Pauliuk, Q. Tu and P. Wolfram.2019. Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. *Environmental Research Letters* 14 (4):043004. doi: 10.1088/1748-9326/ab0fe3.

Hsu, S.-M., P.-H. Hsieh, and S.-T. Yuan. 2013. Roles of 'small-and medium-sized enterprises' in service industry innovation: A case study on leisure agriculture service in tourism regional innovation. *The Service Industries Journal* 33 (11):1068–88. doi: 10.1080/02642069.2011.623773.

IEA (International Energy Agency). 2019a. *The future of hydrogen*. Paris, France. doi: 10.1787/1e0514c4-en.

IEA (International Energy Agency). 2019b. *The future of hydrogen: Seizing today's opportunities*. Paris. https://webstore.iea.org/download/direct/2803?fileName5The_Future_of_Hydrogen.pdf.

IEA (International Energy Agency). 2021. *Net zero by 2050*. Paris: France. https://thegreentimes.co.za/wp-content/uploads/2021/05/net-zero-by-2050.pdf.

Köhler, J., F. W. Geels, F. Kern, J. Markard, E. Onsongo, A. Wieczorek, F. Alkemade, F. Avelino, A. Bergek, F. Boons, et al. 2019. An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions* 31:1–32. doi: 10.1016/j.eist.2019.01.004.

Krishnan, M., H. Samandari, J. Woetzel, S. Smit, D. Pacthod, D. Pinner, T. Nauclér, H. Tai, A. Farr, W. Wu, et al. 2022. *The Net-zero transition: What it would cost, what it could bring*. McKinsey Global Institute.

Leech, N. L., and A. J. Onwuegbuzie. 2007. An array of qualitative data analysis tools: A call for data analysis triangulation. *School Psychology Quarterly* 22 (4):557. doi: 10.1037/1045-3830.22.4.557.

Lewis, M. 2020. *Deep decarbonization. Green hydrogen, net zero, and the future of the EU-ETS*. https://hub.ipe.com/asset-manager/bnp-paribas-asset-management/deep-decarbonization-green-hydrogen-net-zero-and-the-future-of-the-eu-ets/10048519.supplierarticle.

Li, F. G., and S. Pye. 2018. Uncertainty, politics, and technology: Expert perceptions on energy transitions in the United Kingdom. *Energy Research & Social Science* 37:122–32. doi: 10.1016/j.erss.2017.10.003.

Lusch, R. F., and S. Nambisan. 2015. Service innovation. *MIS Quarterly* 39 (1):155–76. https://www.jstor.org/stable/26628345.

Lusch, R. F., and S. L. Vargo. 2014. *The service-dominant logic of marketing: Dialog, debate, and directions*. 1st ed. New York: Routledge.

Malone, P. R. 2013. Executive interview. *The Journal of Applied Management and Entrepreneurship* 18 (1):119. doi: 10.9774/GLEAF.3709.2013.ja.00008.

Markard, J., and D. Rosenbloom. 2022. Phases of the net-zero energy transition and stategies to achieve it. In *Routledge handbook of energy transitions*, ed. A. Kathleen, 102–23. Abingdon, UK: Routledge.

Matthies, B. D., D. D'Amato, S. Berghäll, T. Ekholm, H. Fredrik Hoen, J. Holopainen, J. E. Korhonen, K. Lähtinen, O. Mattila, A. Toppinen, et al. 2016. An ecosystem service-dominant logic?–integrating the ecosystem service approach and the service-dominant logic. *Journal of Cleaner Production* 124:51–64. doi: 10.1016/j.jclepro.2016.02.109.

McCollum, D. L., A. Gambhir, J. Rogelj, and C. Wilson. 2020. Energy modellers should explore extremes more systematically in scenarios. *Nature Energy* 5 (2):104–07. doi: 10.1038/s41560-020-0555-3.

Mele, C., M. Colurcio, T. Russo-Spena, E. Gummesson, C. Mele, and F. Polese. 2014. Research traditions of innovation: Goods-dominant logic, the resource-based approach, and service-dominant logic. *Managing Service Quality* 24 (6):612–42. doi: 10.1108/MSQ-10-2013-0223.

Nemet, G. F., M. W. Callaghan, F. Creutzig, S. Fuss, J. Hartmann, J. Hilaire, W. F. Lamb, J. C. Minx, S. Rogers, and P. Smith. 2018. Negative emissions—part 3: Innovation and upscaling. *Environmental Research Letters* 13 (6):063003. doi: 10.1088/1748-9326/aabff4.

Paula, O., A. Smith, and M. P. Lerman. 2021. Building transparency and trustworthiness in inductive research through computer-aided qualitative data analysis software. *Organizational Research Methods* 24 (1):104–39. doi: 10.1177/1094428119865016.

Pye, S., O. Broad, P. B. Christopher Bataille, H. E. Daly, A. Freeman, R. Gambhir, A. Gambhir, O. Geden, F. Rogan, S. Sanghvi, et al. 2021. Modelling net-zero emissions energy systems requires a change in approach. *Climate Policy* 21 (2):222–31. doi: 10.1080/14693062.2020.1824891.

Ralf, W., M. Archpru Akaka, I. O. Karpen, and J. Hohberger. 2017. The evolution and prospects of service-dominant logic: An investigation of past, present, and future research. *Journal of Service Research* 20 (4):345–61. doi: 10.1177/1094670517715121.

Raphael, S. 2020. *Scotch whisky pathway to net zero. Ricardo Confidential*, ED13298. Glasgow, UK: Ricardo Confidential. https://www.scotch-whisky.org.uk/media/1733/scotch-whisky-net-zero-report.pdf.

Rennie, D. 2023. New research from Scottish enterprise shows potential increase in demand for hydrogen. *Scottish Enterprise*. https://www.scottish-enterprise-mediacentre.com/news/new-research-from-scottish-enterprise-shows-potential-increase-in-demand-for-hydrogen.

Ricardo Confidential. 2020. Scotch whisky pathways to net zero. Report for the Scottish whisky association. SWA) Scotch Whisky Association, Glasgow. https://www.scotch-whisky.org.uk/media/1733/scotch-whisky-net-zero-report.pdf.

Rubalcaba, L., J. Gallego, and P. Den Hertog. 2010. The case of market and system failures in services innovation. *The Service Industries Journal* 30 (4):549–66. doi: 10.1080/02642060903067571.

Runsen, Y. C., L. Javed, A. Memon Minhaj, A. Muhammad, and N. Atif. 2022. The nexus between fiscal decentralization and environmental sustainability in Japan. *Frontiers of Environment Science* 10. doi: 10.3389/fenvs.2022.905461.

Rust, R. T., and M.-H. Huang. 2014. The service revolution and the transformation of marketing science. *Marketing Science* 33 (2):206–21. doi: 10.1287/mksc.2013.0836.

Ruth, M., B. Pivovar, N. Gilroy, J. Stevens, N. Rustagi, R. Boardman, F. Joseck, S. Satyapal, and R. Sarkar. 2017. 'H2@Scale' - an emerging cross-sector opportunity in the USA. *Gas for Energy* 2:22–27.

SDI (Scottish Development International). 2024. Green Whisky: The distilleries turning to hydrogen for net zero in Scotland. Accessed June 14, 2024. https://www.sdi.co.uk/news/green-whisky-the-distilleries-turning-to-hydrogen-for-net-zero-in-scotland#:~:text=Scotland%E2%80%99s%20148%20distilleries%20consume%20around,harness%20zero%2Demission%20energy%20sources.

SG (Scottish Government). 2021. *Scottish energy statistics*. https://scotland.shinyapps.io/Energy.

Shah, S. A. A., S. Quaid Ali Shah, and M. Tahir. 2022. Determinants of CO2 emissions: Exploring the unexplored in low-income countries. *Environmental Science and Pollution Research* 29 (32):48276–84. doi: 10.1007/s11356-022-19319-3.

Sofuoğlu, E., and D. Kirikkaleli. 2023. Towards achieving net zero emission targets and sustainable development goals, can long-term material footprint strategies be a useful tool? *Environmental Science and Pollution Research* 30 (10):26636–49. doi: 10.1007/s11356-022-24078-2.

Staffell, I., D. Scamman, A. V. Abad, P. Balcombe, P. E. Dodds, P. Ekins, N. Shah, and K. R. Ward. 2019. The role of hydrogen and fuel cells in the global energy system. *Energy & Environmental Science* 12 (2):463–91. doi: 10.1039/C8EE01157E.

Stern, J. 2019. *Narratives for natural gas in a decarbonising European energy Market*. Oxford Institute for Energy Studies. https://www.h2knowledgecentre.com/content/policypaper1434.

Stuart, E. A., M. Azur, C. Frangakis, and P. Leaf. 2009. Multiple imputation with large data sets: A case study of the Children's mental health initiative. *American Journal of Epidemiology* 169 (9):1133–39. doi: 10.1093/aje/kwp026.

Suri, H. 2011. Purposeful sampling in qualitative research synthesis. *Qualitative Research Journal* 11 (2):63–75. doi: 10.3316/QRJ1102063.

SWA (Scotch Whisky Association). 2024. *Scotch whisky boosts UK economy by £7.1bn*. https://www.scotch-whisky.org.uk/newsroom/scotch-whisky-boosts-uk-economy-by-71bn/.

UG (UK Government). n.d. Scotland's whisky distilleries ready to go green. Gov.uk. Accessed June 14, 2024. https://www.gov.uk/government/news/scotlands-whisky-distilleries-ready-to-go-green.

UN (United Nations). 2018. *International recommendations for energy statistics (IRES)*. (NY): U.S. United Nations.

UN (United Nations). 2021. COP26: Together for our planet. Accessed June 13, 2024. https://www.un.org/en/climatechange/cop26.

van Cappellen L., H. Croezen, and F. Rooijers. 2018. Feasibility study into blue hydrogen: Technical, economic & sustainability analysis. *CE Delft*.

van der Spek, C. B. Banet, C. Mijndert, P. Gabrielli, W. Goldthorpe, M. Mazzotti, S. T. Munkejord, M. van der Spek, N. A. Røkke, N. Shah, et al. 2022. Perspective on the hydrogen economy as a pathway to reach net-zero CO 2 emissions in Europe. *Energy & Environmental Science* 15 (3):1034–77. doi: 10.1039/D1EE02118D.

van Vuuren, D. P., E. Stehfest, D. E. H. J. Gernaat, J. C. Doelman, M. Van den Berg, M. Harmsen, S. de Boer, L. F. Bouwman, V. Daioglou, O. Y. Edelenbosch, et al. 2017. Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. *Global Environmental Change* 42:237–50. doi: 10.1016/j.gloenvcha.2016.05.008.

Vargo, S. L., and R. F. Lusch. 2004. Evolving to a new dominant logic for marketing. *Journal of Marketing* 68 (1):1–17. doi: 10.1509/jmkg.68.1.1.24036.

Vargo, S. L., and R. F. Lusch. 2008. Service-dominant logic: Continuing the evolution. *Journal of the Academy of Marketing Science* 36 (1):1–10. doi: 10.1007/s11747-007-0069-6.

Vargo, S. L., and R. F. Lusch. 2016. Institutions and axioms: An extension and update of service-dominant logic. *Journal of the Academy of Marketing Science* 44 (1):5–23. doi: 10.1007/s11747-015-0456-3.

Vargo, S. L., and R. F. Lusch. 2017. Service-dominant logic 2025. *International Journal of Research in Marketing* 34 (1):46–67. doi: 10.1016/j.ijresmar.2016.11.001.

Victoria, M., N. Haegel, I. Marius Peters, R. Sinton, A. Jäger-Waldau, C. Del Canizo, C. Breyer, M. Stocks, A. Blakers, I. Kaizuka, et al. 2021. Solar photovoltaics is ready to power a sustainable future. *Joule* 5 (5):1041–56. doi: 10.1016/j.joule.2021.03.005. https://www.cell.com/joule/pdf/S2542-4351(21)00100-8.pdf.

Vink, J., K. Koskela-Huotari, B. Tronvoll, B. Edvardsson, and K. Wetter-Edman. 2021. Service ecosystem design: Propositions, process model, and future research agenda. *Journal of Service Research* 24 (2):168–86. doi: 10.1177/1094670520952537.

Waisman, H., C. Bataille, H. Winkler, F. Jotzo, P. Shukla, M. Colombier, D. Buira, P. Criqui, M. Fischedick, M. Kainuma, et al. 2019. A pathway design framework for national low greenhouse gas emission development strategies. *Nature Climate Change* 9 (4):261–68. doi: 10.1038/s41558-019-0442-8.

Yin, R. K. 2018. *Case study research: Design and methods*, 6th ed. Thousand Oaks, CA: SAGE Publications.