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Review Article

A comparative analysis of biogas and hydrogen, and the impact of the certificates and blockchain new paradigms

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HIGHLIGHTS

- Detailed of the varying methods of production of biogas and hydrogen.
- The varying methods of use of green gases.
- Certification for green gases, and it's benefits.
- How blockchain can complement, and enhance, the use of green gas certification.

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ABSTRACT

Solar and wind energy technologies, due to their nature of weather dependency, have been recognized as not the complete solution for the renewable energy transition. Creating a solution for the short fall is empirical if we are to remove the dependency on fossil fuels and reach net zero targets. The production of hydrogen, biogas and other gases can be produced sustainably, which can also allow for the utilization of waste materials or the ability to store energy and allow a greater positive impact on our environment. However, production of these gases is not always as transparent or environmentally friendly as perceived, so with the aid of certification and blockchain, we can create a system that can guarantee their environmentally positive origin, and ultimately help assist the transition to a greener future. This paper explores the varying production methods, with consideration to their environmental impact, and the implications of the use of certificates and blockchain to monitor production, trade and usage.

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Contents

Introduction

Renewable energy certificates have been introduced in numerous countries worldwide to monitor the production, sale and use of renewable energy. In Europe, this also comprises of the introduction of digital certificates, including the category of biogas or green gas, and encompasses schemes for cross border agreements [77].

In 2012 the European Commission (EC) recognized the energy sector was the primary producer of Greenhouse gas (GHG) emissions and estimated that by 2050 a decarbonised energy sector was possible [41].

Almost a decade later, through research, debate, and discussion, 2021 saw the delivery of the European Green Deal, a strategic plan to reduce GHG through research, legislation and adaption. 2018 figures showed GHG emissions for the energy sector equated to 83% of European emissions [66], and this document set a target to reduce emissions to 55% of 1990's level by increasing renewable energy usage and energy efficiency [30].

This was echoed in the “Fit for 55” package, a package consisting of a set of proposals to realign EU legislation with the climate deal ambitions and reiterate the EU commission's position as a leader in the fight against climate change, including the reduction of emissions to 55% by 2030 [33].

The initial acceleration of the transformation of the energy sector began in 2007 when the EC setup an initiative called the Strategic Energy Technology Plan (SET Plan) [42]. This plan consisted of a number of key research initiatives and paved the way for the development of the European Industrial Bioenergy Initiative to support the advancement of bioenergy technologies [46]. These initiatives encompassed the following ten research/actions:

1. Renewable technologies integrated into the system.
2. Reduce costs of technologies.
3. New technologies and services for consumers
4. Security and resilience of the energy system.
5. Nuclear safety.
6. New technologies and materials for buildings.
7. Energy efficiency for industry.
8. Competitiveness in battery sector and e-mobility.
9. Bioenergy and renewable fuels.
10. Carbon capture, storage, and use.

Even with these initiatives, biofuels usage stalled, with hydro and wind technologies becoming more prominent. In 2018, a surge in the adoption of corporate Power Purchase Agreements (PPA) [48] by multinational businesses saw a demand in the need for origin certification of renewable energies, with an increased interest in biofuels. This was partly due to the revision of the EU Renewable Energy Directive [18], which incorporated the issuing of green certificates for biomass and hydrogen, and the promotion of the European Renewable Gas Registry (ERGAR), founded in 2016 [103].

PPA are bilateral contracts between large companies and renewable energy producers, that guarantees future renewable energy availability, at a predetermined price. The purchased power will be accredited with a Guarantee of Origin (GoO), which can provide a win-win situation, with the company reducing its carbon footprint and the set price providing a financial attractiveness for the seller, even though the use of PPA's do have their own complications. Companies that could not understand how to translate targets in to PPA and sellers overestimating renewable energy generation has led to many companies turning away from PPA due to the energy production uncertainty [48].

GoO are certificates to help distinguish the origin of an energy source, in comparison to a renewable energy certificate, or green certificate, which are used primarily for quota-based systems, such as PPA.

In Europe a framework exists for the GoO, as outlined by the EU directives 2001/77/EC and 2009/28/EC [29], and is free to be interpreted by the member states as required. This has led to differences in quality and market organisation between countries, but inherent standards for GoOs include validity for a year, the location and type of the energy, and whether it relates to cooling, electricity, or heating. The GoO's will expire if not used within the year [57].

The use of blockchain to monitor certificates could be a way to standardise certification, enhance the uptake, due to the transparency and trust, especially when looking at the use in cross border agreements.

By analysing the production of biogas and hydrogen, and how certificates are being utilised at present, we can create a wider understanding on what measures, policy and regulation can be implemented that would encourage the uptake of renewable fuels, certification, and provide a transparent industry. This paper analyses the area of how the industry can apply blockchain to aid this transparency, and provide an energy that is renewable, environmentally friendly and available to all.

Related works

According to Ref. [105], the effective adoption of renewable energy in Europe is “uneven”. While Germany had 25.8% of renewable sources in its energy grid (and 15.9% of nuclear power, and 50% of fossil sources), France had 17.8% from renewables (and 77% from nuclear power) - both countries impacted (as many other countries, mostly impacted in a negative way) by national tariff policies. However, ambitious goals have been set by many countries - again, Germany has a goal of 80% of energy from renewable by 2050 - and biogas will have an important participation in electricity cogeneration. Similar behaviour is found in other parts of the world. For example, in Africa some countries develop, such as Morocco and South Africa, lead the hydrogen economy in the African continent [82,83]. Different scenarios with different political interest or economic viability in several other locations such as Australia, China, Japan, USA and so on [72].

However, in a recent draft proposal [78] in 2022, the European Union (EU) suggests that nuclear energy and gas to be labelled as “green”, or environmentally sustainable economic activities, and, by doing so, opening a way for these technologies to be eligible to funding typically available for net-zero emissions goals of 2050. This vision about nuclear energy is not something necessarily new, as suggested by the International Energy Agency (IEA) [61]. China also proposed a green hydrogen standard [75]. And, again, similar processes seem to be taking place in other locations (e.g., Iceland, Japan, Republic of Korea and so on) [71].

Also, the European Biogas Association (EBA)'s Statistical Report 2020 [8,51] projects a biogas and biomethane potential for the next decades - when compared to 2019. If this sector keeps its growth rate pushed by new incentive policies, it is expected that by 2030, the biogas and biomethane can roughly double its production (reaching 370–467 TWh) and, by 2050, the production can more than quadruple (1008–1020 TWh).

Initiatives such as the EU Renewable Energy Directive [52], establish biogases (biofuels, bioliquids and other combustibles from renewable origin) roles as renewable energy (or other renewables combustibles). Projects like CERTIFHY [16] already proposes an EU-wide Green GoO that will distinguish between low-carbon and effective renewable hydrogen. In a broader certification aspect, the Energy Web [43] and its Green Proofs (a solution for registering and tracking low-carbon products) implement decentralised identifiers, smart contracts and verifiable credentials in order to provide an auditable trail to prove the origin of a given unit of energy.

Also, standardisation efforts are in development – such the European Committee for Standardisation (CEN)'s, and the European Electrotechnical Committee for Standardisation (CENELEC)'s [111] proposal for GoO production of hydrogen. Although some works discuss alternatives, such as Carbon Credit (CC) market coupled with Green Hydrogen Credit (GHC) [26] and a trade framework as a viable alternative to promote or stimulate the international H2 trading, such proposals may still lack the broad acceptance and adoption of blockchain-related technologies and already established certification schemes.

It is important to highlight that blockchain-based solutions always raises concerns about the amount of energy it consumes. Depending on the technology the blockchain solution is based on, the energy consumption differences can be significant. In the work of [109], the authors discuss the most prominent blockchain technologies available in the market and compare how different approaches can bring energy consumption down. Additionally, at the EU level, the European Blockchain Services Infrastructure (EBSI) [28] also point on the direction of energy consumption (and efficiency) of blockchain. Works like [85] explores several methodologies developed to determine how much energy blockchain technologies implementations effectively consume – and also

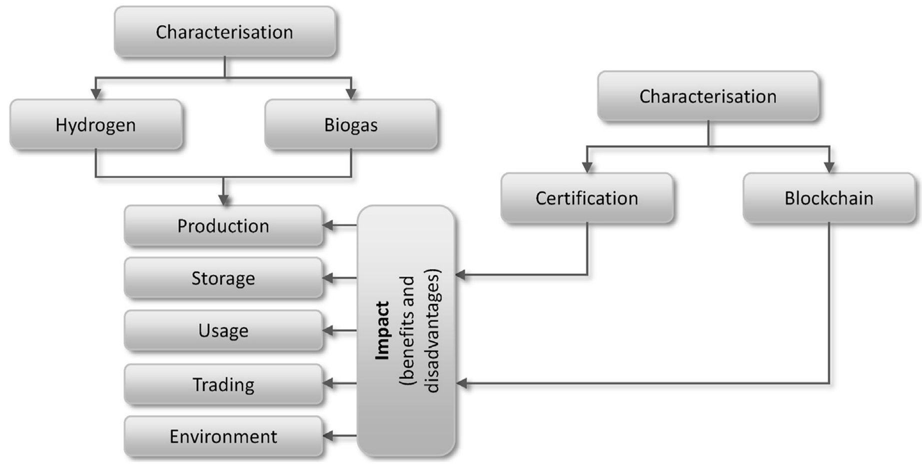

Fig. 1 – Comparative analysis methodology: implicit & explicit.

bring examples of new technologies or implementations that address the consumption issue, such as the Lightning network [92]. Also, the work of [106] point out that new less energy intensive options are becoming more and more common as they are made available by blockchain designers.

Also, other aspects of renewable energy and their social impact, must be highlighted. In Ref. [23], the authors describe other aspects of the adoption of the biogas technologies that goes beyond the usual GHG emission reduction by avoiding deforestation and methane treatment. For example, the money saved by the gas self-production (and potential positive impact on energy poverty) [7,91,117] and the impact on health when replacing indoor cooking with firewood and/or fireplaces (reducing the emissions of smoke and particles) [93,94] by biogas that produces lower emissions when used.

Unfortunately, the European biogas systems are developed almost exclusively on larger scales and there are almost no domestic biogas installations officially approved - due to a number of reasons (e.g., permission vary from country to country, no standards compliance, and safety and operations issues) [53].

The diversity of types (or colours) of hydrogen [4] may also pose a challenge when discussing certificates or GoO. The hydrogen production technology is in constant development and seems to point in the direction of a green hydrogen production cheaper than the other colours (or types) and maybe, in the long run, even cheaper than natural gas [75,89]. Finally, nuclear energy appears as one interesting alternative for green hydrogen production offering a stable base load (since it is under controlled circumstances and given fuel availability) [120]. Although partially loads are not optimal, generation IV reactors are alternatives for power generation without GHG emissions - even when we consider all the security aspects of a nuclear hydrogen production system [47].

Methodology

Methodologically speaking, the comparison process is defined by the differentiation and/or similarity analysis of concepts, processes, or results of any specific event development [97] to support a specific analysis. Furthermore, it can be explicit (when exploits concepts of its domains) or implicit (when applies concepts from somewhere else).

This research uses an explicit comparative analysis, shown in Fig. 1, in what concerns the differences and similarities between biogas and hydrogen production methods and where these gases can be utilised more advantageously (e.g., biogas has huge potential to tackle energy poverty in rural communities, where it can be produced on-site with very little extra additions).

Additionally, an implicit comparative analysis is used to assess the impact and benefits (or disadvantages) of certification and blockchain technologies in the renewable energy sector, and more specifically, for biogas and hydrogen. The objective is to evaluate how these technologies (certification and blockchain) can aid and encourage biogas and hydrogen uptake globally, as we tackle not only GHG but also energy poverty.

From that point on, this paper discusses biogas and hydrogen in what concerns production, storage, specific usages, trading and commercialisation, and its impact on the environment. This thorough analysis is important to identify where the differing gases can be utilised. For example, biogas has huge potential to tackle energy poverty in rural communities, where it can be produced onsite with very little extra additions.

Although blockchain and certification are both relative new adoptions to the energy industry, this paper also analyses the development and application of these technologies to the renewable energy sector and how they can aid and encourage their uptake globally, as we tackle not only GHG but also the replacement of finite fossil fuels and energy poverty.

Biogas and hydrogen

Biogas is produced through a relatively standard method, as seen in Fig. 2, using various feedstocks that could be deemed as waste products from other technologies or industries [101]. Depending on the organic materials in these feedstocks, the delivered result gives differing compositions of the output gas.

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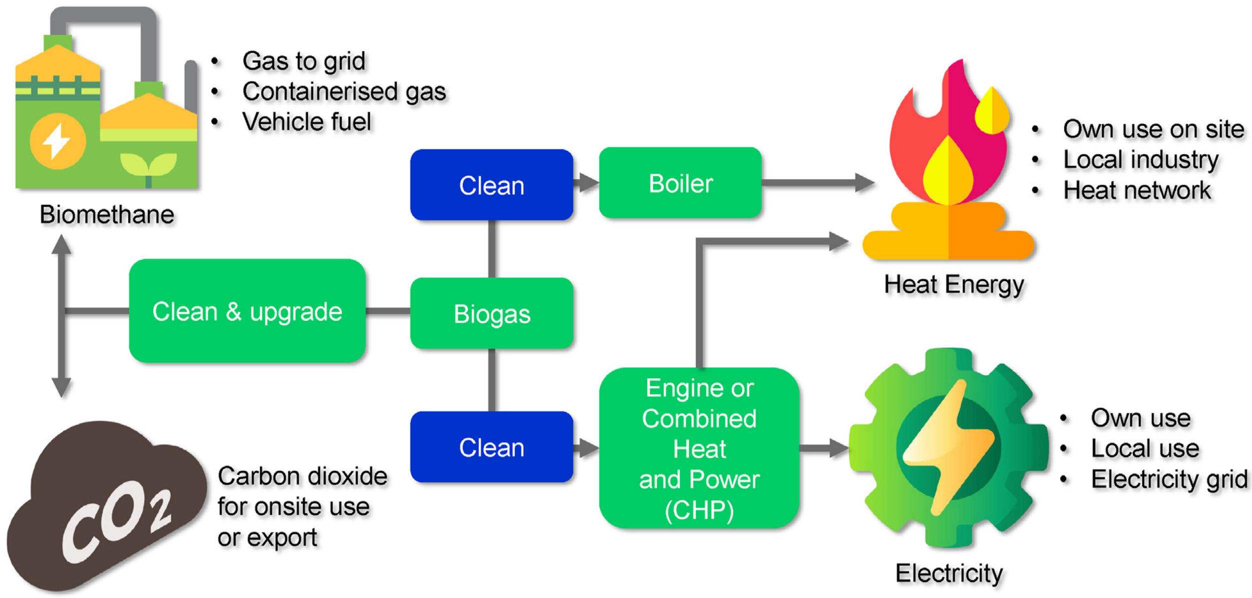

Fig. 2 – Options for biogas use [101].

Table 1 – Biogas advantages and disadvantages.

Advantages	Disadvantages
Domestic and commercial waste that is land filled can create leaching into the soil and water courses around the landfill area. Removing excess organic waste can help reduce this soil and water pollution.	Using purpose grown crops, such as willow and miscanthus (a woody rhizomatous grass) in Ireland, restricts the use of the land for growing edible crops or grazing animals.
Using farmyard or industrial waste on site, can allow the business to have a method onsite to produce gas.	Onsite biogas creation can fluctuate due to composition of feedstock material and environmental factors, such as temperature.
Can be used to tackle energy poverty, as the feedstock fuel can be provided low cost, and energy can be produced at low cost.	Technologically, large scale biogas is in its infancy, and investment and research is needed to create a sustainable industry.

Table 1 shows the several differing advantages and disadvantages of biogas production, this list is not exhaustive.

This compares with the production of hydrogen, where a variety of methods can be used, many of which are defined as non-environmentally friendly. At present these non-environmentally friendly methods are more prominent due to viability and cost, but with the turn away from fossil fuels, and the cost of renewable energy decreasing, the viability of large scale environmentally friendly hydrogen becomes more realistic.

With such a vision of renewable produced hydrogen, 2020 saw a huge development in hydrogen technology, accumulating with the publication of the European Hydrogen Strategy [17], where hydrogen is deemed to be crucial in the energy transition, with the potential for preserving and enhancing industrial and economic competitiveness.

Biogas

Biogas is a type of biofuel, along with ethanol and biodiesel. It is a natural by-product of the decomposition of an organic feedstock material, whether from sewage, landfill or compost, occurring when oxygen is absent, and its output will vary in differing gas compositions depending on its feedstock mixture, giving on average a content of between 50 and 75% methane (CH_4), and 25–50% carbon dioxide, (CO_2).

With an ever-growing worldwide population, we will see an increase of human, animal and food waste produced. Using this by-product to produce biogas is an environmentally friendly method to produce renewable energy and assist the reduction of methane gas released into the atmosphere.

As already mentioned, using different types of feedstocks, i.e., organic materials, will result in the final composition of the biogas, containing varying levels of different compounds, and this in turn can determine how it can be used in differing ways, making it an attractive all-round fuel for renewable transition. The conditions in which the degradation of matter is also important. The process takes four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. These four stages see the breakdown of material using bacteria through a fermentation process to produce the final gases. The conditions in which these bacteria work optimally, include a suitable temperature, pH, salinity as well as the feedstock's ability to decompose rapidly, to provide nutrients for the bacteria [101]. The final product ultimately will have a calorific value proportionate to its methane content, thus any contaminants in the gas must be removed for optimum energy.

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Food waste

Astoundingly, in the United States, 34 million tonnes of food waste were sent to landfill in 2010, accounting for 31% of food bought that year, and in 2013 it was calculated landfilling of food resulted in 18% of US methane emissions [19].

This prompted the US to look at the problem of discarded food waste, resulting in several states banning waste food entering landfill, and alternatives were sought, including using food waste as a feedstock in digestors. One such project was in Massachusetts, where a dairy farm began using food waste mixed with slurry to generate power for the farm. This project was so successful, that the farm began to generate energy for neighbouring properties too [19].

In the Spanish city of Seville, streets are lined with orange trees, of which many bear fruit that goes unwanted. A pilot scheme devised in 2020, has utilised 35 tonnes of these unwanted fallen oranges, and with the aid of the city's water treatment plant, is producing electricity to power approximately 150 homes. The process involves extracting the juice which is added to the wastewater sludge, and this is in turn is user in a digestor to create biogas. It is estimated that if all the city's oranges were used, they could power 73,000 homes [27].

In Ireland, the SEAI's report "increased biomethane scenario" also highlighted that food waste and slurry could be the main feed stocks for digestors in Ireland [102]. One project in Kildare, Ireland, has proved how biogas can be a chain link in a circular economy. Green Generation, a green energy supplier, partnering with Tesco's, a major UK and Ireland supermarket retailer, is using waste food with pig slurry to create biogas and biomethane. The biogas is used to generate electricity, which is sold back to Tesco, and the biomethane is fed back into the national gas network [11].

Slurry and it's dangers

Teagasc, the Irish agriculture and food development authority, estimates that 10% of all agricultural fatalities over the last decade in Ireland are slurry related [1], with the primary causes of death are either drowning or gassing. Slurry tanks allow the fermentation of animal waste in a closed environment, but waste must be agitated to allow for uniform degrading of the material. To do this, farmers open tanks for agitation, and this allows for hydrogen sulphide, H2S, to be released, which is undetectable to the human nose, and can be fatal.

Traditionally once the slurry has degraded it will be spread on farmland as a fertiliser, and this in itself can cause environmental hazards to biodiversity and watercourses. Therefore, use of an anaerobic digestor would allow all decomposition gases to be collected as biogas, and still allow for the final waste output to be used as fertiliser, without the environmental issues, or the risk to human life.

Algae

Algae is considered to be one of the most important organisms in the living world as it creates around 50% of the worlds oxygen from sequestering CO_2 from the atmosphere, as well being an important source for food production, medicine and other sectors.

The advantage of the use of seaweeds over terrestrial plants for biofuels is hugely evident. Without needing to change the use of land, shorter life cycles, non-maintenance, or the need to fertilise makes seaweeds a much more appealing feed stock for biofuel.

As well as just biofuel, certain species of algae can also produce hydrogen under sulphur deprived conditions or via photo fermentation. Photo fermentation is an important chemical process, as it can be used in wastewater treatment to produce hydrogen [110].

Crops

Agricultural crops have the potential to be important for the production of biogas, but this detracts from the growth of food, with change of use of land away from agriculture to feed humans or graze animals. So, where crops are grown for biogas, it increases the importance of a high output of biogas per acre of land and having to create a seasonal crop rotation that allows optimal output per acre of crop. With this in mind, feedstocks that are high in carbohydrates, i.e., sugars, fats and proteins, are considered to provide an optimum biogas output, these would include various root vegetables and grasses, as well as other types of crop residues. So ideally these would be the preferred crop for biogas.

Land fill

Landfill sites produce methane derived principally from discarded food and organic matter. This gas is referred to as landfill gas rather than biogas, due to its breakdown method in the ground, rather than inside a digestor [98]. This methane that is produced can be highly noxious and with the gas formed above ground level in high density, it can be highly flammable.

The United States Clear Air Act requires any landfill of a certain size and above to collect methane gas, and it is estimated, by the US Energy Information Administration, that 0.3% of United States (US) electricity generation comes from this gas [34].

Wastewater

Sludge, the by-product from wastewater treatment plants or industries using large volumes of water, originally was landfilled, used as a land fertiliser, or incinerated, but 2002 European legislation imposed strict laws on its disposal after the treatment plant.

Some industries, such as paper mills, also use anaerobic digestors for generating electricity from their own waste. Paper mills are considered to be highly pollutants due to the high volume of water and electricity they consume, but also the toxic sludge that is produced that can contain chlorinated organics, pathogens and heavy metals [95]. So, these types of industrial facilities utilise the electricity made on site, not only for selling to the grid, but also for its own industrial use by heating the digestors to enhance the process and destroy any pathogens or organics in its own waste [34].

Hydrogen

Hydrogen, with its high energy content per unit mass, is one of the most abundant elements in the universe. Its occurrence happens as a component in more compounds than any other element, and due to this compound form, such as hydrocarbons, to retrieve it as an element, must be done by breaking its bonds from these compounds [96].

	Material	Method	Process
Brown	Coal	Gasification	$CO + H_20 \rightarrow CO_2 + H_2$
Grey	Gas	Steam Methane Reforming	$CH_4 + H_20 \rightarrow CO + 3H_2$
Turquoise	Gas/Methane	Pyrolysis	$CH_4 \rightarrow C + 2H_2$
Blue	Coal/Gas	Steam Methane Reforming/Gasification	$CO + H_20 \rightarrow CO_2 + H_2$
Pink	Water	Electrolysis	$2H_2O \rightarrow 2H + 0_2$
Yellow	Water	Electrolysis	$2H_2O \rightarrow 2H + 0_2$
Green	Water	Electrolysis	$2H_2O \rightarrow 2H + 0_2$

Fig. 3 – Production colours of hydrogen.

As industrial hydrogen production can occur in many ways, hydrogen is known as the gas of many colours, with each colour representing the method of production, as shown in Fig. 3.

Therefore, unlike biogas, or biomethane, hydrogen can be produced more diversely, in which some methods are deemed environmentally friendly and others not. In Europe the Hydrogen Strategy, a legislative framework looking at the inclusion of hydrogen into Europe's energy transition, outlines the long-term goal of renewable hydrogen inclusion, but also short-term outlines supporting low-carbon methods of hydrogen production [31].

This is because for renewable hydrogen to be viable, research must be conducted on the methods and technology to create an economic sustainable viable model, as costs for fossil fuel production are much lower financially with a price of $1.25 per kg of hydrogen compared to the 2030 projected cost of green hydrogen at $2 per kg of hydrogen [12].

Electrical methods of creating hydrogen

Batteries can be utilised for storing excess electricity from a power plant or from the grid, and then allowed to discharge back into the grid when demand is higher than production, or when production is at a minimal. Batteries can be seen perfect for this job, but it only allows for a finite storage of power, and in the long-term this can be impractical as batteries can discharge and suffer degradation as they reach their life span.

Comparatively, the final cost, at present, of hydrogen can be dictated by the cost of electrodes, but beyond that, hydrogen storage has a longer shelf life, is more efficient and a lower production cost as all is required is just water.

Alkaline Electrolysis Cells (AEC) has been the leading way for producing hydrogen. A mature technology, used since the 1920's, with an efficiency of about 80%, but it has a low hydrogen purity and the energy efficiency for the actual production is low [100].

In comparison, Solid Oxide Electrolysis Cells (SOEC) can dramatically reduce the energy used for the electrolysis, and thus increase the hydrogen production efficiency. Even though not a mature technology, much research has been done over the last decade to make them commercially viable [88].

The Proton Exchange Membrane (PEM) cell was developed in the 1960's by General Electric, and subsequently used in NASA's Gemini space missions. Even though they can be more expensive than AEC, they are relatively small that makes PEM more attractive for urban areas and can be seen to be the cell for the future [32,112].

Use of fossil fuels for production

Worldwide, 96% of all hydrogen is produced using fossil fuels, which can be very carbon intensive. Even though the industry recognises that there must be a transition to zero carbon hydrogen production, fossil fuel-based hydrogen production remains favourable due to lower production costs and its establishment in the industry [118].

Brown, black, and grey hydrogen are relatively similar in extraction method, just using different fossil fuels. These methods use Steam Methane Reforming (SMR), which is the most common method of hydrogen extraction, and has been used since the 1930's [32]. Natural gas, accounts for approximately 75% of hydrogen annual production worldwide [60], as it has a high content of methane. Even though this is region specific, using a nickel catalyst methane will react with steam to produce hydrogen, and other gases such as CO_2 and CO. The CO_2 produced is not insignificant, and this form of production generates approximately 830MtCO_2/yr [60].

In comparison, blue hydrogen can be defined as a low carbon production from fossil fuels. This involves the capture of CO_2 during the production process, and even though there is no accepted amount of CO_2 capture to redefine hydrogen production to blue [89], is seen to be a feasible method that can be economically viable helping to achieve climate goals at an acceptable cost [118].

Alternatively, aqua energy is also seen to be an almost environmentally friendly method of producing hydrogen, as the CO_2 produced remains underground. The method of extracting hydrogen involves injecting oxygen into the heavy oil reservoirs, causing a thermochemical reaction, as developed by The University of Calgary and Proton Technologies. The hydrogen can then be brought to the surface, and the carbon oxides can be left in the ground [118].

Greener methods of production

In comparison to using fossil fuels, nuclear methods for hydrogen production are seen to be interesting and promising. Nuclear energy is seen as a replacement for fossil fuel energy as GHG emissions are minimal compared to fossil fuel combustion. Using nuclear plants to generate hydrogen through low temperature electrolysis at off peak times would allow for a high efficiency and low production cost [24]. In the process of SMR the heat generated from nuclear reactors could reduce the use of natural gas by 30% and eliminate the CO_2 emissions [112].

Green hydrogen can be produced through the use of a zero-carbon method. Using a renewable power source to break water into its constituent parts via electrolysis, hydrogen and oxygen, is an economical way of using surplus renewable energy that cannot be stored.

In 2013 the Orkney Islands, Scotland, began producing renewable energy, through wind and tidal, with the goal to sell back surplus to the national grid, yet due to complications with the power connection to the mainland, the island was unable to sell to the national grid, and was left with surplus energy. Like many inshore and o shore islands, all fuels, such as heating oil and diesel, are imported from the mainland, adding extra cost. The Orkney Islands began to look at using the excess energy to provide transport and heating fuel alternatives. Creating hydrogen on the island provided the perfect solution, creating a circular economy, and demonstrating the way forward for hydrogen [54].

Hydrogen from biomass

Hydrogen production from biomass can be categorised into two sections, either biological or thermochemical, and depending on the constitute of the biomass the efficiency output differs.

Thermochemical conversion is based on SMR, and has basically three principal methods:

- Gasification, which requires a high temperature, approximately 1000 °C, with the absence of oxygen, and with an oxidising agent fed to the feedstock.
- Analogous to gasification, pyrolysis requires neither high temperatures nor an oxidising agent. Thus, it is perfect for feedstock with low water content [10].
- Aqueous phase reforming is responsible for dissolving the feedstock molecules and converting the oxygenated compounds to hydrogen [74].

Biohydrogen, hydrogen created from fermentation methods using bacteria, is one of the promising production methods. Even though certain feedstocks, such as wastewater sludge has a low yield (around 6%) due to its heavy metal content [55], if combined with other methods, it's believed this yield could increase [36].

The use of inedible biomass, such as agricultural waste, for the production of hydrogen can be seen as a viable method, as it has minimal impact on food security, and low CO_2 emissions. In countries such as China, 20 million tonnes of corncob, the waste from growing corn, is used for conversion to chemical compounds and hydrogen [10].

Hydrogen from geothermal

In volcanic areas, geothermal resources are shown to have the highest temperature. Drilling to extract the steam can power electricity or heat pumps, and even though hydrogen can be extracted from the steam by other methods, this harnessed power can then be used for electrolysis to generate hydrogen. This method has been demonstrated in Japan and Iceland [55].

The use of the differing gases

Hydrogen and biogas, even though completely diverse from one another, are being utilised in the energy sector for one purpose - to reduce, and eventually replace, the use of fossil fuels. The use of the differing gases can be similar, but at present infrastructure, technology, and other factors, hinder the uptake of the fuels, and their differing features that make them optimum for various uses, and in different scenarios.

Heating

It is estimated that approximately half of the world's energy use is for heating building's thus the use of renewable energy for heating is important for tackling the long-term replacement of fossil fuels. Biogas can be utilised using different methods for heating and cooling, with the advantage that little or no upgrading is needed for a boiler, and it can be injected into a gas network grid system where it complies with regulations and standards of the country. The advantageous nature of not requiring an infrastructure upgrade allows for biogas to be easily integrated into existing system with little disruption to the end customer.

Direct usage of biogas in a domestic boiler can be through combustion or, in a commercial setting, through the use of

Fischer–Tropsch (FT) liquid fuels from SMR. This heat can then be used for heating buildings, cooking, water heating, or being exchanged on a district heat network. Alternatively, it can also be used for Absorption Refrigeration Systems (ARS). These systems consist basically of generator tube, absorption unit, and evaporator and condenser unit and it has been shown that ARS is less expensive than Compression Refrigeration Systems (CRS) when the price of biogas is sufficiently low [20]. Together, these uses can be combined to greater effect. In Ref. [14] a micro tri-generation system based in a diesel-biogas dual fuel engine was used to generate heat for refrigeration and drying, achieving 40% energy efficiency. This would be higher if the CO_2 was removed from the biogas. Gas lighting systems, which today conventionally used bottled gas or propane, can also use biogas.

To facilitate Hydrogen into an existing gas network will require extensive upgrade of existing pipework. Countries, like the UK, have a low-pressure pipework that is predominately made of iron pipes, that to be able to supply hydrogen in this pipe network it will have to be replaced with polyethylene pipes [25], and with 85% of the UK housing stock serviced with natural gas, approximately 284,000 km of pipeline [38], it is a long-term undertaking.

Analysing these difficulties, a recent project "HyDelpoy", conducted by Keele University & others in the UK, has shown that a blend of 20% hydrogen mixed with natural gas is feasible. The study investigated the use of the hydrogen blend with gas cookers and gas boilers, demonstrating the possibility of injecting hydrogen into the gas grid without a fully upgrade of the network [64].

This indicates that the use of hydrogen in the long term, as a replacement for natural gas, is possible, and manufacturers, such as Worcester-Bosch, are developing hydrogen ready boilers, that will operate with the use of 100% hydrogen [113].

Electricity

In basic terms the electrolysis methods used for producing hydrogen can also be used for generating hydrogen. Rather than electricity being used to break water into constitute parts, the electrodes are fed hydrogen, which reacts with oxygen, generating electricity, and creating water as a by-product.

For electrical generation from biogas, a generator set is the best way to convert biogas to electrical energy. Typically, this involves the biogas being used as fuel for a combustion engine, which converts it to mechanical energy that is used to power an electric generator. Diesel engines, gas motors and gas turbines for example can make use of biogas for power.

Combined heat and power

Combined heat and power (CHP), also referred to as cogeneration, is the ability to generate heat and electricity simultaneously. It is seen as an economic and efficient method, as it has two outputs [50]. Typically, natural gas is used for CHP, but more sustainable fuels are now being used such as biogas.

The use of biogas in CHP is considered to be one of the most efficient ways to use it. This is echoed with the fact that biogas does not need to be modified to be utilised in a system and has two outputs, heating and electricity [50], and that where crops are used from biogas, the crops re-sequester CO_2 from the atmosphere for growth [79].

Started in 2021, a project in Greece called White Tiger, has a long-term goal to close all ignite power plants in the West Macedonia region, by replacing them with green hydrogen generating plants [80]. Then with the heat that is generated from the electricity production it is planned that the heat will be used for district heating.

Transport

As a subsection of the energy sector, the transport sector is the highest user of energy in Europe, equating to around 25% of all European energy use, and respectively, 25% approximately of European GHG emissions. As well as domestic vehicles. GHG's are being emitted from heavy good vehicles, and large commercial and public transport vehicles, so, with targets for decrease in GHG emissions, revolutionising the transport sector is a must. This is echoed by the dependency on fossil fuels, with the 92.4% of EU transportation sector using fossil fuels, and unlike other sectors, as population increases, the emissions from the transport sector continues to rise [9]. Biofuels and hydrogen can provide the ability to revolutionise the transport industry, whether on sea, air or land, but they have different features and factors to o er and consider, with the added bonus of neither being dependant on the energy grid long term.

Hydrogen has the ability to be used in fuel cells or in a combustion engine. Hydrogen fuel cell vehicles are seen to have the ability to have a greater advantage over electric battery cars, due to a greater fuel range and the ability to fuel expeditiously.

The preparation of hydrogen fuel for transport has been anticipated, and ISO standard has already been established, ISO 19880-1 [65], outlining requirements of hydrogen fuel standards. This will ensure on the uptake of hydrogen as a transport fuel all vehicles will be manufactured to avail of a standard infrastructure, and vice versa. Even with the ISO standard concerns have been raised over the safety of hydrogen, especially with regards to storage, but it can be viewed as being safer than traditional fossil fuels. Hydrogen can react with various elements and other compounds to create intense exothermic reactions. Due to its small particle size, it can penetrate through various metals and alloys [86], but if it escapes into the atmosphere, it's not harmful to the environment and will disperse quickly due to its small element size and weight.

Two major factors at present are slowing the uptake of hydrogen in the transport sector. Firstly, the lack of infrastructure that exists and expertise, but also secondly, the use of electric vehicles, and an understanding that differing fuel sources would reduce the dependence on the electrical network.

In 2015, it is estimated that the volume of biofuels worldwide used was approximately 132 billion litres. Although these fuels consisted of many differing types, ethanol was predominant with 98 billion litres used, 30 billion litres of bio diesel, and approximately 5 billion litres of hydrogenated vegetable oils [99].

In Europe the use of biomethane as a transport fuel is limited to a small cohort of countries. These include the Nordic countries, Finland, Sweden, Norway and Iceland, and also in central Europe in Germany and Italy [99]. Even though across the world, the use of biogas for transport is becoming a more viable option, it requires a more complex infrastructure [50] and it has sparked a debate on sustainability, due to concerns on feedstocks [99].

The storage and distribution of methane is challenging compared to traditional transport fuels. However, in parts of Europe the infrastructure exists already, as it was built for compressed natural gas. Countries like the UK, that has a natural gas pipeline, can utilise the high-pressure pipeline, that allows pressure drops for distribution pipes, to give liquid biomethane [3].

Yet one huge problem with compressed biomethane is that it will begin to evaporate over a period of time, and can easily leak from an engine, and with huge GHG implications [3]. With this in mind we can see why biogas is seen to be more acceptable for heating and electricity.

With regards to aviation and the maritime sector, two sectors that have emissions that need to be addressed, are still much in development stage, where many challenges still need to be tackled. Hydrogen shows promise for the marine sector, yet it's accepted that it will not gain traction till after 2030 [104].

Certification

Certification is a mechanism to assure the origin and sustainability of green gas [76]. Europe has different types of certifications and, in general, they exist to reflect how the gas is produced, how much GHG is saved, and tracks the biomethane (or green gas) over the whole supply chain [107] - as shown in Fig. 4. But it is important to highlight that the certificates track not the physical flow of the gas as it is injected into the grid. The certificates track the contractual flow to guarantee no double-counting throughout the supply chain.

Green gas certificates support schemes that target the development of a green gas market (trading), by facilitating the production and injection of the generated biomethane into the country's gas grid. Although several European countries already have green gas certification schemes, they are not all necessarily government-approved schemes - but o er reasonable acceptance by the sector. Despite all the differences in market and regulation, some initiatives aim to be compatible with other schemes and, eventually, open an international trade market for green gas.

As an example of a Gas Certification Scheme, Fig. 4 illustrates a model used in Ireland and Germany [22,49]. The biogas producer informs the amount of natural gas fed into the register. Later, an auditor or an environmental agency will check the production on-site in order to confirm the quality, quantity and origin of the produced gas.

The producers and any other intermediaries involved in the gas trading forwards the certificated gas available on the register to other participants (other intermediaries and/or the final consumer). Finally, the consumer receives an extract informing the amount consumed with origin and producer profile. With this certified information, the consumer can apply for payments and reimbursements enacted by statute.

However, certification schemes are not limited exclusively to biomethane. Most of the green hydrogen supply chain initiatives, as mentioned by Ref. [107], also implement a type of certification scheme. Several other initiatives also have been proposed with the use of blockchain (refer to Section Blockchain) as the backbone for the certificates. Table 2 shows a list of projects that utilise certificates or some form of certification.

Examples of this approach can be found in the work of [119] proposed the I-Green (a blockchain-based individual green certificate scheme). In the work of [69] it is proposed a decentralised system for issuing, receiving and verifying Green Energy Certificates for kWh Ownership (GECKO). The research of [15] presents a marketplace simulation based on Ethereum Blockchain to represent units of energy, where prosumers can trade tokenised GoOs green energy. Also, in Ref. [68], the author describes a partnership with American and Australian companies that would essentially establish a stock market for renewable energy certificates.

Blockchain

Blockchain has evolved from the concept of creating online payments on a distributed ledger. Defined as “a shared, immutable ledger that facilitates the process of recording

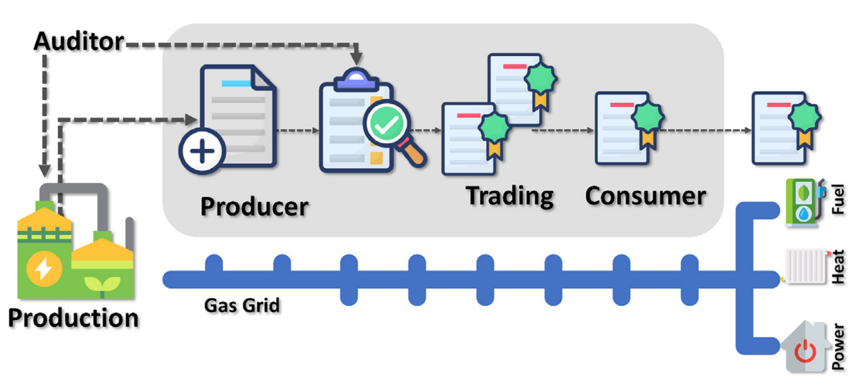

Fig. 4 – Green gas certification scheme.

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Table 2 – Projects focusing on certificates and/or standardisation.

EIHP I and II	Hydrogen	European standards, and analysis of hydrogen standards across Europe [35]
HYRREG	Hydrogen	Southwest European Collaboration Project, promoting a hydrogen-based economy [45]
CERTIFHY	Hydrogen	Cross-Europe project using Guarantee of Origin, with a European database
GreenH2Chain	Hydrogen	Allows for quantification, tracing and monitor of Hydrogen chain
DiBiCoo	Biogas	Aiding the preparation of biogas markets in Europe, and facilitate cross country cooperation [70]
REGATRACE	Biogas	Development of a trading system that allows for the issue and trade of certificates pertain to renewable biomethane/renewable gases.
ERGaR	Biogas	Founded in 2016, the registry allows for cross border transfer of biogas
I Green	Blockchain (Solar)	Smart meters upload the generation and consumption data of users to be stored on blockchain [94], and can be traded with use of its own currency.

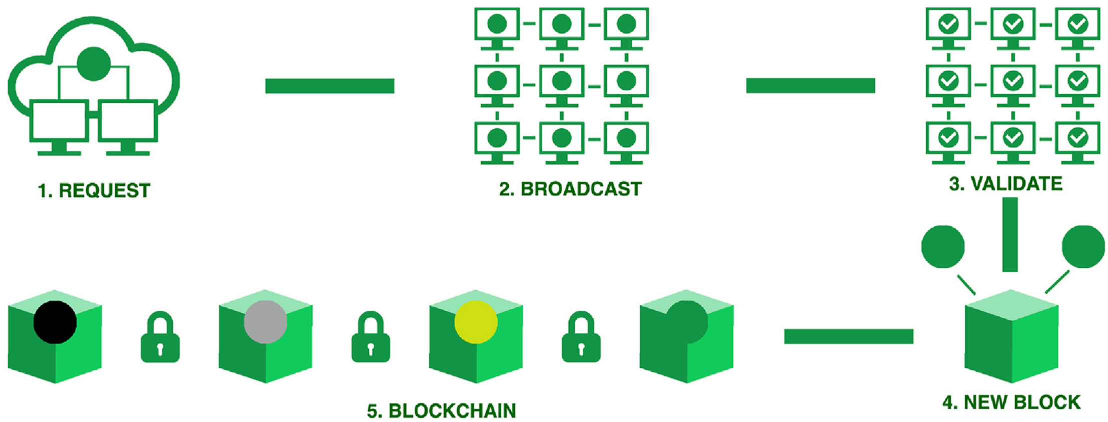

Fig. 5 – How does blockchain work? [67].

transactions and tracking assets in a business network" [59], it is now seen to have the potential of being the backbone technology in many sectors from healthcare to education, financial services to farming.

As the power grid becomes increasingly digitised, with the increased use of smart meters, actuators and other Internet of Things (IoT) devices, management and security of energy data will also become increasingly important.

The use of blockchain, or other emerging distributed ledger technologies, can provide a fail-safe method that enhance customer and prosumer cyber safety. This is illustrated in Fig. 5 on how, in blockchain, hash functions and public-private key cryptography [21] are employed to ensure that if any alterations are made to a block, the hash for that block would be different and therefore provide an indication of a potential malicious activity [2].

In the energy sector, as decentralised energy is coming to the fore [13,37,115], the need for greater traceability is essential to the success of these renewable energy options, such as P2P electricity, biogas, and green hydrogen.

This is where blockchain can be the solution to the problem [5], rather than being seen as a problem that Distribution System Operators (DSO), Transmission System Operators (TSO) or Gas Networks must deal with. While research projects such as EnerPort [108], CENTS [56,62] and Beyond [39] have explored the application of blockchain on P2P electricity trading, this has been quite slow to be applied to the various green gas options that are available. The introduction of blockchain with Renewable Energy Certificate (REC)'s can be adaptive, as blockchain can have potentially change how the energy market is regulated. Blockchain can be seen in basic terms as a legally recognized information carrier, allowing for users throughout the system, to monitor and understand how energy is created, its life span, ending with how it is used, this allows for the blockchain to innately recognise new technologies and the legal framework of a system [6]. This long-term enhanced efficiency of a network, increased reliability, customer protection could disrupt the energy sector and allow for faster digitisation and decarbonisation of the sector. In 2020 it is calculated that 31 million REC issued worldwide through the I-REC Standard [116]. Yet, from this, it is estimated that only 9% of energy blockchain projects relate to certification [90]. Blockchain isn't the only Distributed Ledger Technology (DLT) to be disrupting the energy sector. A DLT based project, Internet of Energy (IEON) [63], using Holochain, is investigating software-based grids that will use an open based protocol that will allow for a scalable network that can create a network where devices communicate amongst themselves. This will allow the grid to self-govern, allowing for an energy balance that is effective [81], and respond to scale.

The future

So far worldwide, 130 countries have a 2050 target to reduce emissions to net zero. The Paris Agreement, a legally binding international treaty on climate change, has seen 110 of the 191 participants, submitting a new updated national action plan to reduce emissions [87] and aid financial assistance to countries that are more vulnerable.

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These national plans – submitted from different countries – contain different concepts on how to reduce emissions, but the EU has set its own targets for its 27 members. July 2021 saw the EU release a set of proposals to revise EU climate legislation, including an emissions trading system that focused on CO_2, N_2O and perfluorocarbons emissions that primarily includes the energy, chemical and aviation sector [40]. Tackling the energy sector from an outside perspective way looks straightforward, but when you consider existing infrastructures and technology adoption rates, it becomes a daunting task.

The use of certification will allow consumers to trace the origins of the energy from its production and, with the use of blockchain, it can be traced throughout the system to its use, creating a whole new industry. Like the EU, China has also created a system of trading emissions, but has experienced problems with high quantities of trading certificates. To tackle the problem, issuing digital "carbon tickets" as part of China Certified Emission Reductions will allow every transaction to be traced using blockchain [114].

Coincidentally, this Chinese project started roughly at the same time IBM started a new blockchain project with Energy Blockchain Labs, in 2017, to help organisations monitor and trade carbon credits, allowing for organisations to record and quantify their environmental impact [58].

The year 2021 saw IBM partner with Mitsubishi to develop CO2NNEX, a blockchain platform that tracks the capture and reuse of CO_2, an important component in carbonated drinks industry or for fire extinguishers – among many other industries [73]. Other projects are in development around the world including the Energy Web Foundation (EWF) blockchain. The EWF have developed an open-source project that is redefining its blockchain to suit the energy market. It has improved the blockchain system to use proof of authority and instils privacy whilst still being able to differentiate nodes, applications and different regulations [44].

Biogas can have real potential for tackling not only climate change, but also the UN sustainable development goals. In developing countries - like South Africa - the use of biogas provides a solution to energy poverty by creating a decentralised energy system. But it falls short of legislation and policy guide-lines to regulate and help project developments [84].

In the transport sector biogas and hydrogen can be an alternative to fossil fuels, along with electric vehicles, to decarbonise it and provide a solution to tackling emissions for heavy good vehicles, public transport, as well as the maritime and aviation sector.

The EU hydrogen strategy sets a vision of converting the natural gas network for hydrogen and providing a framework on how hydrogen can develop in energy transition. It lays a plan on how short-term hydrogen valleys (small geographical areas) can be setup, and how it can, in the long term, create a backbone of a hydrogen network across Europe [17].

Conclusions and discussion

High energy consuming blockchain consensus mechanisms has left many people questioning blockchain's viability for use in the energy sector. Many recent projects are redefining how blockchain, and fundamentally how Distributed Ledger Technologies, operate. Analysis of how they can operate more power efficiently, using renewable energies, and with initiatives like the one by the EWF, there is a valid argument for blockchain to become an instrumental part of the energy industry. Others may argue that blockchain is deemed not necessary, but the use of blockchain with certificates can aid in much more than the vehicle on which certificates travel but provide a basis on how certificates should be developed. This can come in the form of requirements and legislation, where, for example, inter country purchasing may require certain standards to be attained for use on their network, or for consumers to understand where and how their energy was produced.

The development of biogas and hydrogen is becoming increasingly more interesting and promising as technologies develop and gain momentum in use. Both gases show potential for developing as a renewable fuel, but until we begin to develop and utilise them, we cannot begin to understand where they can be used more effectively. With this said, hydrogen shows promise as an energy carrier, by being able to store energy from ex-cess electricity produced from solar or wind farms, converted through electrolysis into a gas that can be stored. Unlike batteries that have a finite life for storage or experience leakage of energy over time, hydrogen can be then used when required, or transported, for differing purposes.

As for biogas, it has the potential to be more than just a fuel, with the ability to use non environmentally compound emitting waste material as a feedstock. This can have an environmental impact not only on air quality, but also on soil and groundwater quality, as chemical leaching is reduced. In farming communities, the slurry will allow farmers to contribute significantly to their sustainability, ecology and aid them financially, whilst helping reduce farm fatalities, and produce sustainable energy.

Biomethane shows promise as a replacement for natural gas, and doesn't require a significant upgrade to present infrastructure, whereas hydrogen would. Yet further research into hydrogen for the transport sector would allow haulage and public transport vehicles to decarbonise and create a roadmap on how to tackle the aviation and maritime sector.

Examples such as Scotland's Orkney Islands communities paving the way for renewable transition show that it is viable with the right mindset, aided with policy, and regulation to create a decentralised and self-sufficient community.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Acronyms and Abbreviations

AEC: Alkaline Electrolysis Cells. 6
ARS: Absorption Refrigeration Systems. 8
CC: Carbon Credit. 2
CEN: European Committee for Standardisation. 2
CENELEC: European Electrotechnical Committee for Standardisation. 2
CHP: Combined heat and power. 8
CRS: Compression Refrigeration Systems. 8
DLT: Distributed Ledger Technology. 10
DSO: Distribution System Operators. 9
EBA: European Biogas Association. 2
EBSI: European Blockchain Services Infrastructure. 2
EC: European Commission. 1
EIG: Energy Informatics Group. 12
ERGAR: European Renewable Gas Registry. 1
EU: European Union. 2, 10, 11
EWF: Energy Web Foundation. 11
FT: Fischer–Tropsch. 8
GHC: Green Hydrogen Credit. 2
GHG: Greenhouse gas. 1–3, 6, 8, 9
GoO: Guarantee of Origin. 1–3, 9
IEA: International Energy Agency. 2
IERC: International Energy Research Centre. 12
IoT: Internet of Things. 9
PEM: Proton Exchange Membrane. 6
PPA: Power Purchase Agreements. 1, 2
REC: Renewable Energy Certificate. 9, 10
SMR: Steam Methane Reforming. 6, 8
SOEC: Solid Oxide Electrolysis Cells. 6
TSO: Transmission System Operators. 9
UCC: University College Cork. 12
US: United States. 5