International Journal of Renewable Energy Resources 13 (2023) 1-13
https://doi.org/10.22452/ijrer.vol13no1.1

PREDICTING POTENTIAL CHALLENGES OF REGIONAL HYDROGEN COOPERATION THROUGH A CASE STUDY OF THE EUROPEAN UNION

Lee Jun Kun*, Sharmili Dhar & Muhammad Nawaz
Global Studies Programme, National University of Singapore, Singapore 138600, Singapore
*e-mail: leejunkun@u.nus.edu

Abstract
Climate disasters will become more common if carbon emissions continue unabated. In response, the United Nations (UN) has called for countries to achieve net-zero carbon emissions by 2050. For many countries, adopting hydrogen energy through imports and regional cooperation is critical to achieving this goal. This study will look at the potential benefits and challenges of regional hydrogen cooperation through a case study of regional hydrogen cooperation in the European Union (EU). The main argument is that the challenges confronting the EU are likely to be encountered elsewhere. The EU provides a particularly favourable environment for regional cooperation. If these challenges were encountered in a favourable environment, they would likely be encountered in less favourable regions as well. The main implication is that other regional cooperations will likely face challenges such as domestic opposition, weak international cooperation in hydrogen R&D, overly lenient carbon emissions accounting, and exacerbated regional inequality.

Keywords: ASEAN, EU, Hydrogen Economy, Energy Transition, Regional Cooperation

LIST OF ABBREVIATIONS

Abbreviation	Explanation	Abbreviation	Explanation
BMJV	Bundesministeriums der Justiz und für Verbraucherschutz (Federal Ministry of Justice and Consumer Protection)	GHG	Greenhouse gases
BP	British Petroleum	GWP	Global warming potential
CCS	Carbon Capture and Storage	H2020	Horizon 2020
CO_2	Carbon dioxide	IRENA	International Renewable Energy Agency
EC	European Commission	MTI	Ministry of Trade and Industry (Singapore)
eCorda	External Common Research Data Warehouse	R&D	Research and development
EU	European Union	RED II	Renewable Energy Directive II
FCH 2 JU	Fuel Cells and Hydrogen 2 Joint Undertaking	SRG	State Representatives Group
gCO_{2eq}/MJ	Grams of carbon dioxide equivalent per megajoule of hydrogen produced using its lower heating value	UN	United Nations
GDP	Gross domestic product		

1. INTRODUCTION

One of the biggest challenges humanity will face in the near future is the impending climate crisis. It is predicted that there would be 83 million excess deaths between 2020 and 2100 if no policy changes are made to reduce carbon emissions (Bressler, 2021). The United Nations (UN) recommends limiting global temperature rise to 1.5 °C and achieving net-zero carbon emissions by 2050 to avert this climate catastrophe (UN, n.d.). Many nations have responded to the UN's call and created national plans to accomplish this. A major pathway for decarbonisation is the adoption of hydrogen energy.

The development of hydrogen technologies represents an opportunity to decarbonise key sectors such as energy. Electricity production is a significant contributor to carbon emissions in many countries. As international concern about the climate crisis grows, countries all over the world are looking for ways to decarbonize their economies. Some countries can decarbonize by switching from fossil fuels to non-carbon emitting renewable energies. However, the availability of renewable energy sources is uneven, and some countries are unable to produce renewable energy locally (MTI, 2022). Importing hydrogen energy is frequently viewed as the most viable decarbonisation pathway for these countries. Hydrogen imports would allow even countries with no local renewable energy resources to access renewable energy and decarbonise their electricity sector.

Despite the benefits of hydrogen energy, the reality is that hydrogen utilisation is currently not extensive global supply chains for clean hydrogen have not developed yet (MTI, 2022). This can be attributed to the various challenges facing widespread hydrogen adoption. This study will examine three of these problems: (1) high costs of hydrogen; (2) debate surrounding blue hydrogen and carbon capture & storage (CCS); and (3) shortage of Guarantee of Origin certifications.

2. CHALLENGES OF HYDROGEN ENERGY

2.1 HIGH COSTS OF HYDROGEN

The current high cost of production is perhaps the most significant barrier to widespread hydrogen adoption producing energy from green hydrogen is several times more expensive than using traditional fossil fuels (Nuñez-Jimenez & De Blasio, 2022). According to IRENA (2022), this costly production is due to the high costs of renewable energy (1, 17). Hydrogen is more expensive and less energy efficient than fossil fuels due to energy losses at each stage of production (IRENA, 2022).

2.2 DEBATE SURROUNDING BLUE HYDROGEN AND CARBON CAPTURE & STORAGE (CCS)

Hydrogen is only as green as its source (Fleming, 2021). It can be either produced “cleanly”, with little to no carbon emissions, or “uncleanly”, with high levels of carbon emissions. The need to differentiate between “clean” and “unclean” hydrogen has given rise to the classification of hydrogen according to the method of production. The three most prominent types of hydrogen can be seen in Table 1. While researchers agree that green hydrogen has great potential for decarbonisation (IRENA, 2022) and grey hydrogen is undesirable, there is a heated debate about the utility of blue hydrogen and its implications for decarbonization efforts (Fleming, 2021).

Table 1: A selected colour-code typology of hydrogen production (IRENA, 2022)

	Green Hydrogen	**Grey Hydrogen**	**Blue Hydrogen**
Process	Electrolysis	Reforming or gasification	Reforming or gasification with CCS
Energy Source	Renewable Energy	Fossil fuels	Fossil fuels
Estimated emissions ($CO_{2\text{-}eq}$/kg)	0	Reforming: 9 – 11 Gasification: 18 - 20	0.4 - 4.5

Note: CO_2-eq/kg refers to carbon dioxide equivalent emitted per kilogram of hydrogen produced

Supporters argue for its potential to emit 25% and 50% less carbon emissions than gasoline and natural gas, respectively, for an equal amount of energy produced (Lloyd et al., 2010). Opponents argue that the viability of CCS and blue hydrogen has yet to be demonstrated at an industrial scale (Howarth & Jacobson, 2021; IRENA, 2022). There are many points of contention surrounding blue hydrogen, and its decarbonisation potential remains a source of debate.

2.3 SHORTAGE OF GUARANTEE OF ORIGIN CERTIFICATIONS

Many importing countries value Guarantee of Origin certifications because they want to use hydrogen to reduce carbon emissions (IRENA, 2022). As previously stated, hydrogen can be produced "cleanly" or with significant amounts of carbon emissions (Bleischwitz & Bader, 2010; Fleming, 2021). According to IRENA (2022), countries that use hydrogen to decarbonize should obtain a Guarantee of Origin certification to ensure that the hydrogen they consume is low-carbon hydrogen (74). While some regions have Guarantee of Origin certifications, IRENA claims that no international certification standard exists (IRENA, 2022). As a result, countries may be unwilling to pay for more expensive hydrogen energy if carbon emissions are not reduced.

3. METHODOLOGY

The challenges detailed in the previous section affect global hydrogen adoption. While global solutions elude us, regional efforts have already been made to tackle them in the EU. The EU is an ideal case study for research into regional hydrogen cooperation because many relevant policies are already in place. This study will look at the regional hydrogen policies in the EU.

3.1 SELECTION OF REGIONAL EUROPEAN UNION (EU) HYDROGEN POLICIES

This study will examine three regional EU hydrogen policies: (1) the Fuel Cells and Hydrogen 2 Joint Undertaking; (2) CertifHy; and (3) the EU CCS Directive. These policies are selected because they were meant to tackle the challenges identified in the literature review. The policies and their respective addressed problems are listed in Table 2.

Table 2: EU regional hydrogen policies and their addressed problems.

Addressed Problem	EU regional hydrogen policy
High cost of hydrogen & Market failure arising from the lack of an established hydrogen market	Fuel Cells and Hydrogen 2 Joint Undertaking
Absence of Guarantee of Origin certification	CertifHy
The debate surrounding blue hydrogen and CCS	EU CCS Directive

The challenges identified in the literature are not exclusive to the EU. Therefore, it is likely that other regions will employ similar solutions to combat these challenges. By analysing policies that are likely to be adapted in other regions, this study hopes to produce policy insights that may be useful to future policymakers.

3.2 LIMITATIONS

While the case study methodology is appropriate, it is imperative to address its limitations. A common criticism of case studies is that the findings produced are non-generalisable (Yin, 2012). Because case studies examine policies in context, the insights derived from EU regional policies may not apply anywhere else in the world due to the EU's uniquely favourable traits for regional cooperation like its shared currency and single market. However, because of this, a case study of the EU presents would be particularly useful in identifying the challenges of regional hydrogen cooperation, as well as the limits of benefits. The choice of a case study with highly favourable conditions is useful, because if a case with highly favourable conditions faces challenges, then cases with less favourable conditions would likely face the same challenges or worse (Flyvbjerg, 2006). If the EU faces challenges with regional cooperation, then other regions would be likely to face those challenges as well.

4. POLICY ANALYSIS

This paper will look at the benefits and drawbacks of regional hydrogen cooperation. The examined policies and their corresponding addressed problem are listed in Table 3.

Table 3: EU regional hydrogen policies and their identified benefits and challenges.

Addressed Problem(s)	Required Action	Regional Policy(s)	Benefits	Challenges
High cost of hydrogen & Market failure arising from the lack of an established hydrogen market	Reduce hydrogen costs through research Spur the creation of a thriving hydrogen market by overcoming the first-mover problem	The FCH 2 JU established under H2020	Demonstrated potential of hydrogen technologies, boosting investor confidence	Worsened regional inequality Does not address fragmented research

Absence of Guarantee of Origin certification	Create a system of certifications to verify the origins of traded hydrogen	CertifHy	Pioneered regional Guarantee of Origin systems for hydrogen	Measurements of greenhouse gas emissions might be too lenient and inadequate
The debate surrounding blue hydrogen and CCS	Establishment of common rules and norms to ensure that EU member states adopt the same accepted standards, ensuring interoperability	EU CCS Directive	Common regional standards and goals were set	Domestic resistance against regional policies resulted in inconsistent implementation

4.1 FUEL CELLS AND HYDROGEN 2 JOINT UNDERTAKING

The high cost of hydrogen is a significant impediment to widespread deployment. Hydrogen fuel, particularly green hydrogen, is more expensive than typical fossil fuels (Howarth & Jacobson, 2021; IRENA, 2022). This discourages profit-seeking private enterprises from adopting hydrogen technology, hence limiting their use. R&D is predicted to reduce hydrogen costs by improving the efficiency of electrolysers and other hydrogen technologies (Bleischwitz & Bader, 2010; IRENA, 2022; Nuñez-Jimenez & De Blasio, 2022). However, the cost of hydrogen today remains high. Another impediment to widespread hydrogen adoption is a market failure caused by the first-mover disadvantage — also known as the "Chicken and Egg" problem. There will be little demand for hydrogen until significant infrastructure investment is made, but no infrastructure investment will be made unless adequate future demand is demonstrated (IRENA, 2022). An example is hydrogen fuel cell automobiles (Szőke, 2021). Automobile makers are cautious to build hydrogen vehicles because such vehicles currently have few refuelling facilities — a lack of infrastructure. Energy providers, on the other hand, are reluctant to build hydrogen refuelling stations as there are few hydrogen vehicles on the road — little demand. Sustainable growth in the hydrogen market does not occur because no firm will accept the first-mover risk and invest first.

To address these issues, the EU established the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) (EC, 2017; EU, 2014), which is tasked with implementing public-private partnerships for hydrogen research to develop “strong, sustainable, and globally competitive fuel cells and hydrogen sector in the Union" and reducing the costs of hydrogen and fuel cells (EU, 2014). The three most relevant FCH 2 JU tasks are displayed in Fig.1:

Fig.1 Tasks of the FCH 2 JU (EU, 2014)

In sum, the FCH 2 JU would (a) provide grants to fund R&D into hydrogen to reduce costs of hydrogen production. The grant monies were obtained from EU member states as well as additional participating entities (EU, 2014). The resulting proliferation of hydrogen R&D would (b) build investor confidence in the industry, helping to overcome the first-mover problem. The FCH 2 JU would also (c) “facilitate interaction between industry, universities and research centres” to promote cooperation in R&D. This is handled by the FCH 2 JU States Representatives Group, which is tasked with identifying areas of cooperation, coordinating hydrogen technology deployment, and preventing research overlap.

Overall, the FCH 2 JU appears to have largely fulfilled its tasks a 2017 evaluation of the FCH 2 JU determined that the initiative is on pace to overcome these problems, claiming that it has "a robust portfolio of projects congruent with the precise objectives set in the law" (EC, 2017). Unfortunately, the FCH 2 JU has encountered difficulties. Two obstacles have emerged that have reduced the effectiveness of this regional cooperation: (1) inequity in funding and benefit; and (2) limited success in employing regional cooperation to develop regional R&D coordination.

Table 4: Comparisons between GDP per capita and benefits gained from the H2020 program. Calculated from data compiled from multiple sources (EC, 2022; eCorda, 2022; Eurostat, 2023).

Country	GDP Per Capita (2019)	Percentage of total H2020 funding received (2014-2020)	Percentage contributed to EU budget (2013-2019)	Difference	Return per Euro
Luxembourg	83,590	0.326%	0.276%	0.050%	1.181
Ireland	59,560	1.950%	1.532%	0.417%	1.272
Denmark	48,970	2.858%	1.963%	0.894%	1.456
Sweden	44,180	3.749%	2.803%	0.946%	1.338
Netherlands	41,980	8.725%	4.042%	4.683%	2.159
Austria	38,090	3.170%	2.472%	0.698%	1.282
Finland	37,150	2.491%	1.619%	0.872%	1.539
Belgium	36,110	5.504%	3.179%	2.326%	1.733
Germany	35,950	16.403%	20.709%	-4.306%	0.792
France	33,250	12.067%	17.116%	-5.049%	0.705
United Kingdom	32,910	12.724%	11.762%	0.961%	1.082
Italy	27,230	9.232%	12.488%	-3.257%	0.739
Cyprus	25,500	0.515%	0.146%	0.369%	3.519
Spain	25,180	10.337%	8.346%	1.991%	1.239
Malta	22,880	0.061%	0.075%	-0.015%	0.804
Slovenia	20,770	0.616%	0.305%	0.310%	2.016
Portugal	18,670	1.866%	1.394%	0.473%	1.339
Czechia	18,460	0.831%	1.264%	-0.433%	0.657
Greece	17,780	2.782%	1.313%	1.469%	2.119
Slovakia	15,960	0.222%	0.584%	-0.362%	0.380
Estonia	15,410	0.444%	0.165%	0.279%	2.696
Lithuania	14,060	0.155%	0.285%	-0.130%	0.543
Hungary	13,310	0.600%	0.827%	-0.227%	0.725
Poland	13,070	1.209%	3.207%	-1.997%	0.377
Croatia	12,710	0.224%	0.325%	-0.101%	0.689
Latvia	12,540	0.189%	0.196%	-0.006%	0.967
Romania	9,300	0.488%	1.237%	-0.749%	0.394
Bulgaria	6,630	0.262%	0.369%	-0.107%	0.710

According to statistics acquired from the FCH 2 JU, the programme has financial and benefit disparities. Established under the Horizon 2020 (H2020) program (EU, 2014), the FCH 2 JU was intended to be a regional initiative to fund FCH research across the EU; all EU nations have funded and supported the programme. However, as seen in Table 4, not all countries profited equally from the effort. Some member states benefited from the initiative, receiving more funds than their fair contribution to the EU budget. Some member states received less funding than their fair commitment. While uneven financial distribution is to be expected, a problem occurs when this unevenness exacerbates existing inequalities.

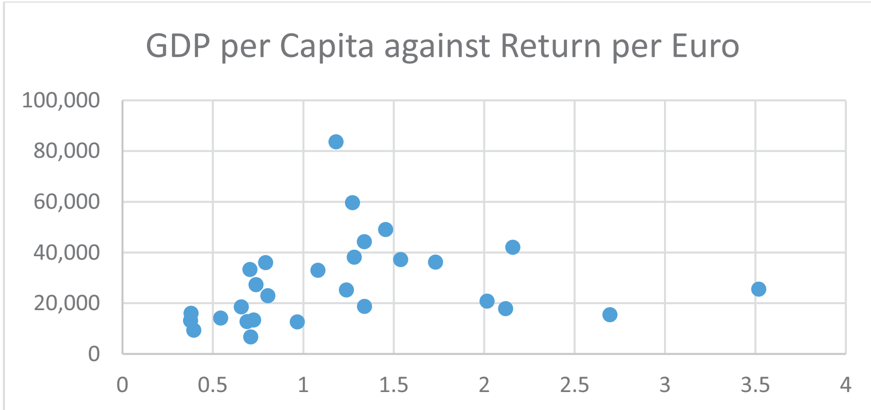

Figure 2. Scatterplot of 2019 GDP per Capita against funding acquired per Euro contribution. Calculated from data compiled from multiple sources (EC, 2022; eCorda, 2022; Eurostat, 2023).

A cursory examination of Figure 2 reveals a favourable link between GDP per capita and Return per Euro. In other words, EU member states with high GDP per capita are more likely to gain more than €1 in financing for every €1 contributed a net profit. Member countries with lower GDP per capita numbers, on the other hand, are more likely to incur a net loss. This unequal funding allocation may exacerbate regional inequality – this funding scheme may accidentally constitute a transfer of wealth from weaker economies to stronger ones. Furthermore, not only do larger economies receive more money, but they are also more likely to profit from financed research because it is funded by local businesses. These factors combined might lead to the FCH 2 JU worsening regional inequality within the EU.

The second recognised difficulty is the ineffectiveness of regional collaboration in producing regional R&D coordination. The FCH 2 JU's Tasks (see Figure 1) indicate that the initiative is intended to promote interaction between industry, universities, and research centres (EU, 2014). This is intended to encourage firms and research institutes to collaborate in hydrogen research, thereby eliminating redundancy and enhancing efficiency. While the FCH 2 Joint Undertaking has been successful in funding research, it has been ineffective in promoting regional R&D cooperation. An evaluation of the FCH 2 JU by the EC says that "in terms of addressing fragmentation within Europe, the obstacles of ensuring enhanced coordination between Member States' FCH research and innovation assistance remain. There is little indication that the State Representatives Group's (SRG's) effectiveness in this area is changing" (EC, 2017). This may be related to the fact that R&D under the FCH 2 JU is an industry-led project (EC, 2017). While the EU fund a project, the research is carried out by private institutes and businesses. While there are benefits to collaboration, these private enterprises may be competing for the same niche in a developing industry. For example, over half of the FCH 2 JU award funds were dedicated to showing the viability of fuel cell buses (EC, 2017). Private enterprises may be unwilling to collaborate with competitors and risk a lesser market share. Furthermore, while the EU has permeable borders, other constraints like distance and language may make regional cooperation in hydrogen research time and resources expensive. These issues may have hindered commercial companies from collaborating on hydrogen research.

These two challenges of regional cooperation in hydrogen research are likely not unique to the EU; other regions that engage in regional hydrogen cooperation are likely to find that their hydrogen research funding programmes exacerbate regional inequality and fail to adequately spur regional coordination. The EU is far from the only region in the world with significant income inequality. If other countries attempted regional collaboration in hydrogen research, funding would most likely be channelled to larger and wealthier economies due to their efficiency. This could worsen regional inequality by shifting research money from smaller to larger nations, increasing the likelihood that larger countries will have first access to established technology. In terms of regional coordination, if the EU cannot generate regional R&D coordination, other areas are unlikely to succeed. The EU's single market facilitates private-sector cooperation by lowering trade and talent-transfer barriers. Yet, despite these benefits, the EU's regional efforts have failed to stimulate regional R&D coordination. Some locations with higher hurdles to R&D cooperation, such as non-single markets, have a lesser likelihood of regional R&D cooperation.

4.2 CERTIFHY

The lack of Guarantee of Origin certifications was another barrier to widespread hydrogen adoption. These certifications are critical for organizations that are using hydrogen to achieve their climate goals. Guarantee of Origin certifications would verify the hydrogen fuel production process and grade them based on how much CO_2 and other greenhouse gases are emitted. This would allow countries and businesses to ensure that their use of hydrogen is paying environmental dividends. However, as of this writing, no global system has been established (IRENA, 2022). Nonetheless, a regional system does exist — the EU has established a regional Guarantee of Origin certification scheme. The absence of a Guarantee of Origin certification is the third issue that the EU hoped to address through regional cooperation. To that end, they established the CertifHy scheme, a Guarantee of Origin certification (CertifHy, 2022a, 4, 8). The CertifHy Scheme document concisely summarizes CeritfHy's goals and function (refer to Appendix A). CertifHy can issue two Certification Labels: (1) "CertifHy Low Carbon Hydrogen" and (2) "CertifHy Green Hydrogen" (CertifHy, 2022a). To obtain the CertifHy Low-Carbon Certification, the hydrogen produced must not exceed 36.4 grams of carbon dioxide equivalent per megajoule of hydrogen using its lower heating value (gCO_{2eq}/MJ) (CertifHy, 2022b). Low-Carbon Hydrogen was defined as hydrogen produced while emitting 60% less greenhouse gases than grey hydrogen, which emits 91 gCO_{2eq}/MJ. To obtain the CertifHy Green Hydrogen certification, the primary source of energy in hydrogen production must be renewable. Wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave, and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas are recognized renewable energy sources (CertifHy, 2022b). Furthermore, the CertifHy Green Hydrogen certification includes the CertifHy Low-Carbon Hydrogen criteria. In other words, any unit of hydrogen must also meet the CertifHy Low-Carbon Hydrogen certification of not exceeding 36.4 gCO_{2eq}/MJ emitted to meet the CertifHy Green Hydrogen certification.

CertifHy can validate the environmental impact of each batch of hydrogen fuel with these certifications. This enables hydrogen customers to determine how their hydrogen is produced. This removes a barrier to hydrogen adoption by ensuring that countries' and businesses' decision to pay more for hydrogen fuel is contributing to their decarbonisation efforts. While CertifHy has certainly contributed to widespread hydrogen adoption, its contribution to decarbonisation efforts is limited by its lenient measurement of the greenhouse gas effect from CO_2 equivalents such as methane. Methane is a greenhouse gas emitted during the production of grey hydrogen and some low-carbon hydrogens, such as blue hydrogen (Howarth & Jacobson, 2021, 1676-1678). In the case of methane, CertifHy applies the standards established in Annex V of the EU Renewable Energy Directive II (RED II) (adelphi & Öko-Institut, 2021), which equates the greenhouse gas effect of 1 unit of methane to 25 units of CO_2 over 100 years (EU, 2018). Methane has a global warming potential (GWP_{100}) of 25. But this number is too low — one unit of methane has a much stronger greenhouse gas effect than 25 units of CO_2. Table 5 lists some alternative values:

Table 5. List of possible values for measuring the greenhouse gas effect of methane. Data was compiled from multiple sources (EU, 2018, 152; IPCC, 2021).

Source	Value	Notes
RED II	25 GWP_{100}	Currently in use
IPCC	30 GWP_{100}	2021 updated value
IPCC	82.5 GWP_{20}	2021 updated value Uses a 20-year timescale instead of a 100

A 2021 Intergovernmental Panel on Climate Change (IPCC) report revised methane's greenhouse gas effect to 30 GWP_{100} (IPCC, 2021, 1017). CertifHy's value is out of date and too low. One possible reason for this is that CertifHy's greenhouse gases (GHG) calculations must be developed "in collaboration with its stakeholders" (CertifHy, n.d.). CertifHy, as a regional organisation, is likely to have many stakeholders from across the EU. As a result, updating calculations and methodology would necessitate extensive consultations. As a result of these lengthy discussions, the certifications might continue to use outdated definitions and values, reducing their effectiveness. The value of CertifHy in preventing a climate crisis could be increased further by using the GWP_{20} value for GHG calculations rather than the GWP_{100} value. The GWP_{20} value measures the effect of greenhouse gas over 20 years, unlike the GWP_{100}, which measures it over 100 years. This value is more appropriate as reducing the GHG effect over the next 20 years is critical in avoiding a climate crisis. This changes the calculations drastically for some gases like methane, which have a short half-life of only 12 years, but an intense greenhouse gas effect during its lifespan (Howarth & Jacobson, 2021). According to the IPCC, while methane's GWP_{100} value is 30, its GWP_{20} value is 82.5 (IPCC, 2021). This change would drastically increase the calculated effect of methane. A single unit of methane would no longer be equal to 25 units of CO_2 — it would be equal to 82.5 units. This would make low-carbon certification of methane-emitting hydrogen production processes more difficult, but it would make certification more accurate in measuring the actual greenhouse gas effect and its impact on our climate goals. However, the current CertifHy values are far too lenient in measuring methane's greenhouse gas effects.

This issue of leniency in measuring methane's greenhouse gas effects is likely to spread to other regions if they decide to implement a similar regional Guarantee of Origin certification. According to IRENA, countries with more natural gas reserves are more likely to influence their methodologies to underreport their carbon emissions in terms of methane (IRENA, 2022). Natural gas use in hydrogen production typically results in significant methane emissions (IRENA, 2022). These emissions could come in the form of fugitive methane. Fugitive methane is produced by both accidental leaks and deliberate venting processes (Howarth & Jacobson, 2021). Countries can help support their natural gas industries by underreporting methane. Countries with large natural gas reserves are more likely to be reliant on their natural gas industries, and thus underreport methane.

Table 6. Percentage share of global proven natural gas reserves in 2020 by region (BP, 2021).

Region	Share of global natural gas reserves in 2020
North America	8.1%
South & Central America	4.2%
Europe EU	1.7% 0.2%
Commonwealth of Independent States	30.1%
Middle East	40.3%
Africa	6.9%
Asia-Pacific	8.8%

More countries with large natural gas reserves in regional cooperation would make it more likely that methane is underreported, as more countries would favour lenient guidelines. As shown in Table 5, the CertifHy program employed one of the more lenient methane measurements even though the EU has the world's lowest proven natural gas reserve levels. According to Table 6, the EU holds only 0.2% of global proven natural gas reserves. All other regions have more reserves. As a result, all other regions would have the incentive to adopt a more lenient methane measurement than the EU, which some argue is already inadequate. As a result, other regional hydrogen standards collaborations are likely to produce methane measurement standards that are as, if not more, lenient than the EU standards. This could result in underreporting of actual greenhouse gas emissions from hydrogen production. If the EU, which has the least incentive to underreport methane, adopts a lenient measurement of the greenhouse gas effects of methane, it stands to reason that other regions with a stronger incentive will do the same, if not more so.

4.3 EUROPEAN UNION CARBON CAPTURE & STORAGE DIRECTIVE

For the EU to coordinate on their hydrogen policies, the harmonisation of their stances on the controversial blue hydrogen and CCS issue is essential. CCS (or Carbon Capture and Storage) is a technology that is integral to blue hydrogen production. It is used to capture the carbon emissions generated by fossil-fuel based hydrogen production methods, like steam-methane reformation. This captured carbon is then stored underground in geological formations. It is CCS that renders blue hydrogen "low-carbon". However, CCS is controversial due to its questionable viability at an industrial scale, and the potential risks and side-effects of storing carbon dioxide underground. The EU Directive on geological carbon dioxide storage (hereafter: EU CCS Directive), was implemented to harmonise stances among member states and for the future utilisation of blue hydrogen and CCS.

However, a case study of the EU CCS Directive reveals the limitations of regional hydrogen cooperation, even in a region as conducive to regional cooperation like the EU. Even if the EU has decided to set regional standards, it is not a given that its member states will implement them in their intended form. This is evident in German opposition to CCS, which is a critical component of blue hydrogen production.

As mentioned in the literature review section, CCS and blue hydrogen are controversial due to the dubious viability of carbon capture and long-term CO_2 storage underground (Howarth & Jacobson, 2021). CCS attitudes and openness differ across the EU, with Germany in particular having strong domestic opposition to CCS (Shogenova et al., 2013). This disparity in national attitudes has had an impact on the implementation of regional policies. The EU attempted to coordinate CCS implementation in 2009 with the EU CCS Directive. The CCS Directive is a legally binding agreement that "establishes a legal framework for environmentally safe geological storage of carbon dioxide (CO_2) to contribute to climate change mitigation" (EC, 2009). Its goal was to lay the groundwork for large-scale regional CCS deployment, which could account for 15% of the EU's 2030 decarbonisation targets (EC, 2009). However, domestic opposition to CCS has hampered that goal, resulting in the CCS Directive's delayed and watered-down implementation.

Germany is an example of this. The German public and Green Party were strongly opposed to CCS (Shogenova et al., 2013), citing concerns about feasibility and environmental consequences. This opposition led to a slow transposition of the CCS Directive into German law even though the Directive entered into force in 2009, Germany only transposed it in 2012 after the EC applied pressure. Even after the CCS Directive was transposed into German law, it had to be watered down to appease domestic opposition.

Table 7. Differences between the EU CCS Directive and the implemented German CCS law. Source: (EC, 2009; Fleming, 2017).

Article 1 of the EU CCS Directive	**Article 1 of German CCS law (translation provided by Fleming, 2017)**
“This Directive establishes a legal framework for the environmentally safe geological storage of carbon dioxide (CO_2) to contribute to the fight against climate change. The purpose of environmentally safe geological storage of CO_2 is permanent containment of CO_2 in such a way as to prevent and, where this is not possible, eliminate as far as possible negative effects and any risk to the environment and human health.”	“this law serves to safeguard the permanent storage of CO_2 in underground geological formations for the protection of humans and the environment, but also with responsibility for future generations. It is, tentatively, regulating the research, piloting and demonstration of technologies for the permanent storage of CO_2 in underground geological formations”

There are two significant differences between regional and German laws. To begin, the German CCS law emphasizes the law's tentative nature, presumably to appease domestic opposition by leaving room for repeal. Second, under German CCS law, CCS can only be used for research, piloting, and demonstration of CCS technologies (Krämer, 2011). Notably, this excludes commercial applications of CCS technology (Fleming, 2017, 246). Excluding commercial CCS use would severely impede large-scale adoption of CCS technology, potentially jeopardizing the EU's 2030 decarbonisation goals. Furthermore, under Article 2 of the German CCS law, additional restrictions on CO_2 storage in Germany were imposed. A proposed bill for the German CCS law imposed a limit on overall CO2 storage in Germany in 2011. On German soil, only 8 million tons of CO_2 could be stored (Krämer, 2011). When Germany's CCS legislation was finally passed in 2012, this limit was cut in half to 4 million tons (BMJV, 2021) (refer to Appendix B). Germany was able to do this because Article 4 of the EU CCS Directive allowed its member states to determine the level of carbon storage within their territories (refer to Appendix C). Even though the EU CCS laws allow states to decide whether to allow carbon storage on their respective territories, German lawmakers' watering down of the regional law due to domestic resistance has reduced the effectiveness of regional cooperation on CCS technologies as a compromise. Domestic opposition to controversial issues such as carbon capture is expected in regions outside of the EU. According to IRENA, countries will be divided on the blue hydrogen debate based on domestic natural gas reserves (IRENA, 2022, 76). Countries with large natural gas reserves and infrastructure would be more favourable to blue hydrogen and CCS, which use more natural gas. In contrast, countries with limited natural gas reserves, such as Germany, are likely to face domestic opposition due to concerns about CCS and blue hydrogen viability. Domestic opposition to some hydrogen technologies may stymie regional cooperation.

Even when CCS laws are legally binding, domestic opposition hampered regional policy implementation, resulting in a domestic law that is incompatible with the regional policy of greater CCS utilization. In areas where regional laws are not legally binding, the likelihood of policy delay or change due to domestic opposition is greater. This is especially important because regional treaties outside of the EU are likely to be non-binding. While the EU has a long history of legally binding agreements, other regional organizations, such as ASEAN, are more likely to adopt non-binding agreements that are less likely to be strictly followed. If the EU has struggled with inconsistent regional policy implementation due to domestic opposition, other regional organizations will likely face similar difficulties.

5. CONCLUSION

5.1 SUMMARY AND IMPLICATION OF THE STUDY

This study identified some of the benefits and challenges associated with EU regional hydrogen policies through case studies. A brief examination of the EU's regional hydrogen policies discovered that these policies were generally successful in addressing the issues for which they were designed. The FCH 2 JU demonstrated the potential of hydrogen technologies, boosting investor confidence and assisting in overcoming the first-mover disadvantage. And CertifHy was successful in establishing a hydrogen certification scheme to provide hydrogen Guarantees of Origin. Whilst these successes in the EU are ones to be celebrated, we must be aware that EU successes might not be achievable in other regions.

The primary limitation of these findings is that a case study methodology was used — the findings of this research are highly contextualized, and their applicability to other regions is unknown. The findings concerning the benefits of regional hydrogen cooperation, in particular, may not apply to other regions. The EU is a one-of-a-kind example of regional cooperation. The EU, with its single market, porous borders, and official regional governing body, is a region uniquely conducive to regional cooperation. In other words, the benefits enjoyed by the EU may not be available to other regions with less favourable conditions.

However, the EU's uniquely favourable conditions also imply that the challenges it faces are likely to be shared by other regions. Because the EU has such favourable conditions for regional hydrogen cooperation, the fact that it still faces these challenges implies that other regions will most likely face them as well. Despite the EU's ability to create legally binding regional agreements, domestic opposition to regional policies resulted in inconsistent hydrogen policy implementation. Despite having a porous border and a single currency, the EU has yet to achieve greater regional cooperation in hydrogen R&D. Despite having few regional natural gas reserves, the EU has adopted greenhouse gas emission measurements that are too lenient and favourable to natural gas emissions. Furthermore, the EU regional policy of funding hydrogen R&D exacerbated regional inequality by allowing its wealthier countries to receive more funding than its poorer ones. Because the EU is not the only region affected by regional inequality, this challenge is likely to be met elsewhere as well.

The main implication of this study is that if other regions embark on hydrogen initiatives similar to the ones examined in this study, they will most likely face similar challenges. Other regions are likely to utilise policies similar to those that were analysed in this study — this is because the analysed policies are designed to tackle hydrogen problems that are not exclusive to the EU. If policymakers in other regions are interested in establishing these regional hydrogen policies, they should consider these potential challenges.

5.2 FUTURE RESEARCH DIRECTIONS

A study into developing policy solutions to address the identified challenges would greatly benefit this field of research. While this study has identified potential challenges that other regional hydrogen policies may face, it has not proposed any solutions. A study into developing solutions to these identified problems would be a logical next step, greatly assisting policymakers in overcoming these issues and allowing regional hydrogen cooperation to proceed with fewer challenges.

REFERENCES

Adelphi & Öko-Institut. (2021). Critical Review of the IPHE Working Paper “Methodology for Determining the GHG emissions associated with the Production of hydrogen”. Raffaele Piria, Franziska Teichmann, Jens Honnen, Jakob Eckardt, Christoph Heinemann, Dominik Seebach, and Hauke Hermann. adelphi: https://www.adelphi.de/en/publication/critical-review-iphe-working-paper-%E2%80%9Cmethodology-determining-ghg-emissions-associated.

Bleischwitz, R, & Bader, N. (2010). “Policies for the Transition towards a Hydrogen Economy: the EU Case.” Energy Policy 38, no. 10: 5388–98.

British Petroleum [BP]. (2021). Statistical Review of World Energy 2021. BP: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf.

Bundesministeriums der Justiz und für Verbraucherschutz [BMJV]. (2021). Gesetz zur Demonstration der dauerhaften Speicherung von Kohlendioxid (Kohlendioxid-Speicherungsgesetz - KSpG). Bundesministeriums der Justiz. v. 10.8.2021 I 3436. BMJV: https://www.gesetze-im-internet.de/kspg/.

CertifHy. (n.d.) "Focus: GHG calculation and allocation." Certification Schemes. https://www.certifhy.eu/go-definition/.

CertifHy. (2022a). CertifHy Scheme. Clean Hydrogen Partnership: https://www.certifhy.eu/wp-content/uploads/2022/06/CertifHy_Scheme-Document_V2.0_2022-04-28_endorsed_CLEAN.pdf.

CertifHy. (2022b). CertifHy Scheme Subsidiary Document: CertifHy-SD Hydrogen Criteria. Clean Hydrogen Partnership: https://www.certifhy.eu/wp-content/uploads/2022/06/CertifHy_H2-criteria-definition_V2.0_2022-04-28_endorsed_CLEAN-1.pdf.

European Commission [EC]. (2009). Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006. EC. Official Journal of the European Union no. 140. Brussels, Belgium. EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0031.

European Commission. (2017). Interim Evaluation of the Fuel Cells and Hydrogen 2 Joint Undertaking (2014-2016) operating under Horizon 2020. Ana Sofia Caires Sousa Branco, John Loughhead, Annelie Carlson, Piotr Bujło, and Renate Lemke. Publications Office of the European Union: https://op.europa.eu/en/publication-detail/-/publication/8c99f6c7-ac9e-11e7-837e-01aa75ed71a1/language-en.

European Commission. (2022). EU spending and revenue - Data 2000-2021. EC: https://commission.europa.eu/strategy-and-policy/eu-budget/long-term-eu-budget/2014-2020/spending-and-revenue_en.

European Union [EU]. (2014). Council Regulation (EU) No 559/2014 of 6 May 2014 establishing the Fuel Cells and Hydrogen 2 Joint Undertaking. EU. Official Journal of the European Union no. 169. Brussels, Belgium. EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0559.

European Union. (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. EU. Official Journal of the European Union no. 328. Brussels, Belgium. EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG.

Eurostat. (2023). Real GDP per capita. Eurostat: https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table.

External Common Research Data Warehouse [eCorda]. (2022). "Participation in Programmes". Europa. Assessed February 17, 2023. https://webgate.ec.europa.eu/dashboard/sense/app/a976d168-2023-41d8-acec-e77640154726/sheet/d23bba31-e385-4cc0-975e-a67059972142/state/analysis.

Fleming, R. (2017). Shale Gas, the Environment and Energy Security: a New Framework for Energy Regulation. Northampton, MA: Edward Elgar Publishing.

Fleming, R. (2021). "Clean or Renewable - Hydrogen and Power-to-Gas in EU Energy Law." Journal of Energy & Natural Resources Law 39, no. 1: 43–63.

Flyvbjerg, B. (2006). "Five misunderstandings about case-study research." Qualitative inquiry 12, no. 2: 219-245.

Howarth, R. W., & Jacobson, M. Z. (2021). "How Green Is Blue Hydrogen?" Energy Science & Engineering 9, no. 10: 1676–87.

Intergovernmental Panel on Climate Change [IPCC]. (2021). Climate Change 2021: The Physical Science Basis Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press: https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf.

International Renewable Energy Agency [IRENA]. 2022. Geopolitics of the Energy Transformation: The Hydrogen Factor. Abu Dhabi, United Arab Emirates: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen.

Krämer, L. (2011). Case studies on the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide. London: Centre for Law and the Environment, Carbon Capture Legal Programme: 1-31.

Lloyd, C. A., Pike, E., & Baral, A. (2010) "Renewable Hydrogen Production." In Hydrogen and Fuel Cells: Fundamentals, Technologies and Applications, edited by Detlef Stolten, 465-488. (Weinheim, Germany: Wiley-VCH).

Ministry of Trade and Industry Singapore [MTI]. 2022. "Singapore's National Hydrogen Strategy." MTI: https://www.mti.gov.sg/-/media/MTI/HPO/Singapore-Hydrogen-Strategy/ebrochure_HPO_Oct_26.pdf

Nuñez-Jimenez, A., & Blasio, N., D. (2022). "Competitive and Secure Renewable Hydrogen Markets: Three Strategic Scenarios for the European Union." International Journal of Hydrogen Energy 47, no. 84: 35553–70.

Shogenova, A, Piessens, K., Ivask, J., Shogenov, K., Martínez, R., Flornes, K. M., Poulsen, N. E., et al. (2013). "CCS Directive Transposition into National Laws in Europe: Progress and Problems by the End of 2011." Energy Procedia 37: 7723–31.

Szőke, E. (Nov 23, 2021). "We have to overcome the chicken-egg dilemma to effectively deploy hydrogen in transport," CE Energy News: https://ceenergynews.com/hydrogen/we-have-to-overcome-the-chicken-egg-dilemma-to-effectively-deploy-hydrogen-in-transport/.

United Nations [UN]. (n.d.) "Net Zero Coalition | United Nations." The United Nations: https://www.un.org/en/climatechange/net-zero-coalition.

Yin, R. K. Applications of Case Study Research. 3rd ed. Thousand Oaks, Calif: SAGE, 2012.

Appendix A: Excerpt of CertifHy Scheme: Chapter 3 — CertifHy Goal and Mission.
Source: (CertifHy, 2022a, 4, 8)

Start of excerpt:

3 CertifHy Goal and Mission

CertifHy's mission is to advance and facilitate the production, procurement, and use of Hydrogen fulfilling that meets stringent environmental criteria to protect the climate and improve the living conditions of humankind.

CertifHy wishes to contribute to and promote environmentally, socially and economically sustainable production of Hydrogen for all applications such as energy, mobility, chemical conversion, etc.

CertifHy has established a high-quality European Certificate scheme to achieve this, covering the entire upstream supply chain to the production device exit gate at the defined quality and providing the framework for ensuring transparent information. It was created and is constantly reviewed and improved through a multi-stakeholder dialogue.

End of Excerpt

Appendix B: Excerpt of German CCS law: Chapter 1, Article 2 — Scope of the regulation
Source: (BMJV, 2021, 4) (Translation by author)

Start of excerpt:

(2) Carbon dioxide storage facilities may only be approved

1. for which a complete application has been submitted to the competent authority by 31 December 2016 at the latest,
2. for which no more than 1.3 million tonnes of carbon dioxide are stored annually, and
3. insofar as an overall storage volume of 4 million tonnes of carbon dioxide per year is not exceeded within the territorial scope of this Act.

End of excerpt

Appendix C: Excerpt of EU CCS Directive: Article 4 — Selection of storage sites
Source: (EC, 2009, 119)

Start of excerpt:

Article 4: **Selection of storage sites**

1. Member States shall retain the right to determine the areas from which storage sites may be selected under the requirements of this Directive. This includes the right of Member States not to allow for any storage in parts or in the whole of their territory.

End of excerpt