HyTrEc2
Hydrogen Transport Economy for the North Sea Region

Interreg
North Sea Region
HyTrEc2
European Regional Development Fund
EUROPEAN UNION

A Study of a Green Hydrogen Economy for Rural Areas Throughout the North Sea Region

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March 2022

Nomenclature

AE	Alkaline electrolysis
AI	Artificial Intelligence
AR	Augmented Reality
CHP	Combined heat and power
COP26	(26th) United Nations Climate Change Conference
ETS	Emissions Trading System
EU	European Union
FIT	Feed-in Tariff
GB	Great Britain
GH2	Green Hydrogen
GHG	Greenhouse Gases
HEI	Higher Education Institution
ICT	Information and communication technologies
IEA	International Energy Agency
IOT	Internet of Things
IT	Information Technology
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelised Cost of Energy (LCOE)
ML	Machine Learning
MW	Megawatt
MWh	Megawatt hour
NIP	National Innovation Programme Hydrogen and Fuel Cell Technology (DE)
OECD	Organisation for Economic Co-operation and Development
P2G	Power-to-gas
P-2-X	Power-to-X
PEM	Proton exchange membrane
PV	(Solar) photovoltaic
REI II	Renewable Energy Directive (Recast)
SME	Small and medium-sized enterprise
SOE	Electrolysis and solid oxide electrolysis cell
STEM	Science, Technology, Engineering & Mathematics
TRL	Technology readiness level
VET	Vocational Education and Training

Contents

Introduction

The North Sea Region (NSR) has a unique opportunity to develop a cost-effective, integrated hydrogen ecosystem to become a global leader in hydrogen developments, and to accelerate its net-zero targets with substantial momentum. The availability of low-cost, green hydrogen (GH2) and the creation of supply chain(s) will unlock demand from transport, heat and power sectors across the NSR, enabling both public and private investment in infrastructure and facilitating the development of local supply chains and expertise. This study signifies that the reach of economy-wide climate neutrality cannot rely on carbon removal only – and that all public and private pathways for doing so require significant skills development for managing and successfully deploying emissions reduction through GH2.

1.1 Objectives of the study

This study presents the current state of play for renewable or green hydrogen (GH2), offering guidance on its future research and market advancement in rural areas of the NSR; however, it could be considered elsewhere in the NSR. Given the current political and business momentum of GH2, with several policies and projects being planned or already being deployed, the study addresses the prospects of scaling up technologies and bringing down costs to allow GH2 to become widely used in NSR rural areas. Creating a local GH2 industry has become an important energy strategy ambition of many states in Northern Germany. As this study demonstrates, GH2 can play a role in the overall energy mix, which is similarly split among the manufacturing industry, buildings (i.e., residential, commercial and public) and transport.

The study explores the prospects of a pragmatic and actionable implementation plans for taking advantage of this increasing momentum. It focuses on GH2's strengths of being light, storable, energy-dense and free of direct emissions of pollutants or GHG. It also refers to GH2's foreseen contributions to decarbonisation in transportation, (heating of) residential buildings and power generation. The conversion to GH2 by implementing already installed boilers ready for future GH2 use constitutes a viable solution for greening home heating. Replacing natural gas with a GH2 mix is a painless and effortless solution for citizens who require an alternative infrastructure solution at their homes (e.g., boiler, in-house pipelines, cooking appliances) and in their streets (pipelines and compressors). Given the wide number of GH2 uses, the present study lays out where several factors are standing now and how GH2 can realise its potential in attaining a clean, secure and affordable energy future through production of GH2 generated in rural areas. In this context, it is required across NSR regions that policies and incentives centred on GH2 are introduced, with business and skills development in GH2 equally attended to by policy makers.

1.2 Organisation of the study

Chapter 1 of the study sets the stage for exploring GH2 in the Study. Chapter 2 presents the special characteristics of GH2 as a powerful energy alternative for a decarbonisation strategy, such as those required for achieving the ambitious 2050 targets (i.e., achieving net-zero carbon emissions across EU Member States by 2050). The study also outlines the growth and development of the GH2 markets in Northern Germany and in certain leading countries in the NSR. Chapter 3 highlights attained targets and prospects for further development of GH2 and offers a brief glimpse into the technological developments and applications supporting the production and use of GH2 throughout Northern European countries.

Chapter 4 analyses the current and future impact of GH2 in the realm of post-COVID recovery and sustainability. More importantly, it addresses the need for preparing a workforce to meet the technological challenges of a GH2 economy, as it has been clearly depicted in a survey undertaken by the Interreg North Sea Region HyTrEc2 project; this survey was used to also develop results within other project deliverables.

Finally, Chapter 5 underlines near-term actions required for creating viable opportunities for scaling up GH2 and building on existing industries, infrastructure and policies. In this section, special attention is given on the survey data, which suggests the NSR requires to establish a knowledgeable workforce ready to fulfil the advanced skills demand for GH2 and Industry 4.0 manufacturing deployment.

2.0 Background

The EU's undertaking for decarbonisation has been strongly strengthened by the changing weather patterns of more frequent, unpredictable, extreme weather events that demand new sophisticated clean technologies. The NSR requires a substantial economic recovery opportunity to build a more competitive, inclusive and green economy – where clean energy is one of the potential areas for growth, especially in rural NSR areas. In parallel, the NSR is moving forward to the Fourth Industrial Revolution and digitisation in order to meet climate change goals. This implies that new challenges for specialised employment must be met. New skills are vital for enabling individuals to thrive in an increasingly complex, interconnected and rapidly changing society. A workforce with innovative and competitive competencies has a great potential to enjoy higher levels of trust, better health outcomes and a higher quality of life[1]. Notably, main sources of GHG emissions in rural areas are agriculture, transport and energy supply, with residential use of fuel – used primarily for heating – and smaller sectors making up the rest.

[1] https://www.oecd-ilibrary.org/sites/85c17d98-en/index.html?itemId=/content/component/85c17d98-en

Without doubt, energy efficiency, renewable power, and GH2 can reduce emissions. However, aviation, shipping, long-distance trucking and agriculture are difficult to decarbonise due to their high energy density fuel requirements. Green hydrogen can meet these needs because it can be used where it is produced or can be transported elsewhere[2]. Unlike batteries that are unable to store large quantities of electricity for extended periods of time, GH2 can be produced from excess renewable energy and stored in large amounts for a long time. More importantly, GH2 can be used with fuel cells to power anything that uses electricity, such as electric vehicles and electronic devices. GH2 needs to be cooled to 253˚C to liquefy, or compressed to 700 times atmospheric pressure, to be delivered as a compressed gas. Currently, GH2 is transported through dedicated pipelines, low-temperature liquid tanker trucks, in tube trailers that carry gaseous GH2, or by rail or barge. Recent text in the UK shows that GH2 can be safely distributed via the natural gas infrastructure, when no more than 22% of it being blended with the natural gas[3].

GH2 is not yet a market-ready solution of scale, but it has the potential to play a major role in decarbonisation the longer term. In Northern Germany GH2 is not perceived as an alternative to, or in competition with. Rather, renewable electricity and GH2 are both considered to be inter-dependent elements of an overall integrated clean energy strategy, basically constituting a holistic energy systems approach. Hence, renewable electricity, in which rural areas of Northern Germany has an abundance of potential, is likely to be the major source for GH2 production in the future, especially given the curtailment problem of wind power. Therefore, GH2 can obviously play a major role in providing the storage and flexibility capabilities that a renewable power generation system will need in the longer term, functioning as the so-called balancer. In order to do so, GH2 decarbonisation solutions require collaborative working across energy sectors to develop complementary energy strategies, actions, and activities. These can pave the way for a GH2 economy providing an immense opportunity for NSR rural locations and its neighbouring regions to become a global lead on key zero-carbon technologies and a testbed for innovative applications and services.

The future of GH2 across the entire NSR appears to be bright – that is, it shall serve as a central player in a holistic future decarbonisation solution. With a number of countries, such as Germany and the Netherlands, making ambitious statements on a hydrogen future and supporting this with significant funding. For instance, Germany has committed approximately a €9 billion package for hydrogen projects and major companies have taken shares in fuel cell and electrolyser companies[4]. Simple

[2] https://www.sciencedirect.com/topics/engineering/green-hydrogen
[3] Hydrogen is vital to tackling climate change - HyDeploy
[4] https://www.dw.com/en/germany-and-hydrogen-9-billion-to-spend-as-strategy-is-revealed/a-53719746

economics suggests that this could lead to significant cost reductions in equipment, as there is a move from bespoke manufacture to large volume manufacture.

2.1 Uses of green hydrogen

The entire NSR must transition toward a new sustainable energy system, given Europe's net-zero 2050 targets. In doing so, green hydrogen can play many important roles. Hydrogen is a clean and safe energy carrier that can be used as a fuel in transportation and electricity production, as well as a feedstock for industry. GH2 can be produced from green electricity by electrolysis, from biogas by steam reforming or from biomass through gasification. Like natural gas, hydrogen can be transported by ships and trucks or via pipelines. Hydrogen can be compressed or liquefied and can easily be converted into a liquid chemical or fuel, such as ammonia or methanol and e-methanol. From an industrial perspective, ammonia or methanol can also be stored in tanks, which also effectively stores hydrogen. Fuel cells and electrolysis are enabling technologies that will increase the use of hydrogen.

2.2 The characteristics of GH2

Alternative green energy sources such as hydrogen, solar, wind, wave, geothermal, etc., are being considered as plausible providers for meeting the growing demand for clean energy across the NSR. However, none of these energy sources except hydrogen has all the desirable qualities to replace petroleum and natural gas. There are several reasons for this. Some sources, for one, are only intermittently available, whereas others are available away from the end user and therefore cannot be used as fuel for transportation. Hydrogen is plentiful in the form of water in oceans, lakes and rivers. Hydrogen is also found in numerous substances like natural gas, methanol, etc. It is also the cheapest synthetic fuel to manufacture per unit of energy stored within it.

Over the last decade, there has been an increasing intensity of research efforts to investigate the various aspects of the hydrogen energy system, such as its production, storage and transport and its applications in a holistic energy system. Currently, most of the world's hydrogen is generated from hydrocarbon sources, such as through the reforming of natural gas or coal gasification. The CO_2 emissions of this production, however, are still relatively high.

Hydrogen is a colourless, odourless and extremely flammable gas and the smallest and simplest member of the chemical family. The thermal properties of hydrogen, both liquid and gaseous state, compare favourably with petrol and natural gas. For a given amount of energy, hydrogen weighs about one-third of the fossil fuel equivalent – but it is larger. Meanwhile, GH2 in liquid form occupies 3.8 times the volume occupied by petrol, and in gaseous form it occupies 3.6 times the volume occupied by natural gas. Its high flame speed and wide flammability limits make hydrogen a particularly ideal fuel for combustion and has many applications. However, the energy carrier hydrogen and the use of fuel cells can contribute significantly to achieve many environment objectives, especially in the areas of energy security and air quality; e.g., through the reduction of greenhouse gas emissions and industrial competitiveness, if produced in an environmentally friendly way.

2.2.1 The need to establish a GH2 market in rural areas

The maturity of the hydrogen market is still exceptionally low in rural Northern Germany, whilst the market across the NSR is exhibiting significant and rapid growth and some predictions are showing cost competitive applications within a five-year – but more likely ten-year – timeframe. Given the need to decarbonise many sectors across NSR, there will be a need for GH2 to accomplish this and, also, to support in balancing the grid infrastructure[5]. The fact that there is not a ready market for GH2 to be consumed in rural parts of Norther Germany represents an excellent opportunity. Thus, there is a need to identify and establish a GH2 growth opportunities and incorporating this into projects, keeping in mind that any design project should take into consideration end users' needs.

Notably, the holistic nature of a GH2 market in rural Northern Germany carries a number of risks and obstacles that are imperative to address before certain projects could become commercially viable. Internationally, there is a current debate over how quickly green hydrogen will become economically viable.

The high level of international interest in the GH2 market would suggest that there will be a significant market for GH2 projects, especially given the need to decarbonise to a net zero economy by 2050[6].

2.2.2 European context

The European Union's commitment to hydrogen comes with an economic rationale, driven by approximately 35% cost reduction in GH2 over the past five years, and additional 55% cost reduction of GH2 expected by 2030. The EU sees scaling up GH2 production as a cost-effective decarbonisation solution as it becomes cost-competitive with grey hydrogen and fossil fuels towards 2030. It is expected that the cost reduction of green hydrogen production will result in select applications achieving commercial viability before 2030 at forecast carbon prices (e.g., €60 to €100 per tonne of CO_2 equivalent for steel).

The EU further calls attention to the importance of acting now, given that investments made over the next decade will only impact emissions in 2050 with investment cycles often at 25 years; this in turn would support the zero-emission targets being set for 2050. Notably, many north-western and central EU countries have similar commitments to reduce emissions from transport, heat and power

[5] https://www.nweurope.eu/projects/project-search/gencomm-generating-energy-secure-communities/news/hydrogen-the-fuel-of-the-future-is-becoming-a-reality-in-ireland/
[6] Hydrogen – Analysis - IEA

generation. Each one presents diverse strategic and policy drivers to ensure that change happens, depending on the country's specific circumstances. A selection of similar northern EU countries shall be introduced demonstrating their GH2 policies and GH2 deployments[7].

The following chapters shall explore various European countries in the context of building a GH2 economy in the NSR.

2.2.3 Denmark

Most Danish power generation comes from wind and bioenergy. The large-scale use of combined heat and power (CHP) plants, heat storage, and wind power promotes the integration of heat and electricity systems. Denmark has a wide range of policies in place to encourage renewable energy in a variety of sectors[8]. Renewable energy sources are promoted through a premium tariff and net-metering. A separate fund supports pilot project windmill construction. Renewable heating projects are tax exempt for the production, supply and use of energy, which has significantly incentivised the renewable energy market in Denmark. The use of biogas for heating purposes is supported through a direct tariff.

The main incentive for renewable energy use in transport is a quota system. Selling of biogas for transport purposes is supported through a direct tariff. Additionally, renewable energy has priority access to grid networks.

Policy in Denmark aims to achieve 50% of power generation through renewable energy by 2030. Interestingly enough, Energinet has conducted a system report for Danish energy solutions in 2035 that had led to recommendations and projections for anticipating significant production of hydrogen via electrolysis[9]. Notably, Denmark's national integrated energy and climate plan[10] specifically highlights H2 as a transport fuel and as a large-scale energy store, in addition to outlining the importance of H2 to facilitate energy sector coupling. Ringfenced finance has been allocated to the tune of 128 million DKK for two Power-to-X (P-2-X) projects. Both projects include large-scale production and storage of H2 under "near market" conditions. It must be noted that the term "near market" foresees that these two P-2-X projects will create the conditions were H2 becomes economically viable.

[7] https://www.iea.org/regions/europe
[8] http://www.res-legal.eu/search-by-country/denmark/
[9] https://energinet.dk/Analyse-og-Forskning/Analyser/RS-Analyse-Marts-2018-Systemperspektiv-2035
[10] https://kefm.dk/media/12980/denmarks-national-energy-and-climate-plan.pdf

2.2.4 Germany

The energy transformation (Energiewende) describes Germany's plan to achieve a low carbon nuclear-free economy, and it has been active for several years now[11]. Plans to phase out nuclear power are well on track. More recently, Germany's response to the COVID-19 pandemic includes a €7 billion support package for H2 research and deployment projects[12]. Germany has stated its ambition to be the first country in the world with a fully operational H2 refuelling infrastructure – an ambition the Danish network has arguably already achieved, although comparisons should not be drawn due to the variation in country size. The German H2 production policy is focused on the development of H2 production from renewables. Germany is pioneering the development of power-to-gas (P-2-X).

The German Federal Government, along with the science and industry sectors, supports the development of fuel cell and H2 technologies in Germany in the form of a strategic alliance known as The National Innovation Programme Hydrogen and Fuel Cell Technology (NIP), providing them with cutting-edge research in this field. The Federal Government plans to reduce greenhouse gas emissions, more importantly they wish to be a global leader in doing so. Developing a German H2 market will promote H2 as a decarbonisation option not just for Germany but for German trading partners as well. This is a key contribution to global climate change mitigation. As of June 2020, the Federal German Government National H2 Strategy has served as the principal document to guide H2 policy development across Germany[13]. The strategy is supported by a wide variety of existing policies and funding programmes, as well as committing the German government to future policy development and spending in developing a hydrogen economy.

2.2.5 Norway

With the significant potential of renewables and the historic importance of natural gas production, Norway sees H2 as an important part of its future energy transition. Norway's geography and population density make the development of H2 infrastructure a challenge. Currently, H2 activity is mainly focused on Oslo, although there is sporadic activity across the country. Marine transport is a major area of interest given Norway's shipping heritage and it entails the production of H2 from natural gas. Norway has recently updated its climate emissions targets and now anticipates renewables will reduce all emissions by 55% compared to 1990 levels[14] of all energy requirements by

[11] https://www.cleanenergywire.org/germanys-energiewende-brief

[12] https://www.businessgreen.com/news/4016109/green-recovery-germany-unveils-plans-eur40bn-climate-spending-surge

[13] https://www.bmbf.de/files/bmwi_Nationale Wasserstoffstrategie_Eng_s01.pdf

[14] https://www.regjeringen.no/en/aktuelt/norge-forsterker-klimamalet-for-2030-til-minst-50-prosent-og-opp-mot-55-prosent/id2689679/

2030. "Power for Change" is the key document driving Norwegian energy policy[15]; additionally, a national H2 strategy was recently announced[16]. The document contains an obligatory and significant commitment to H2 adoption, with pilot and demonstration projects becoming a key element in policy execution. Industry and transport, with high-speed passenger ferries highlighted as adopters of H2 technology, are the clear ambitions of Norway with regard to its H2 strategy.

2.2.6 Sweden

Sweden aligns mainly with EU policies on climate change mitigation and aims to achieve net-zero emissions by 2045. Sweden has the lowest share of fossil fuels in its primary energy supply among all International Energy Agency (IEA) member countries, and the second-lowest carbon-intensive economy[17]. The reduction in carbon intensity has been achieved despite Sweden having a relatively high per capita energy use. In 2018, the average renewables contribution to primary electricity generation was 54%[18].

Notably, CO_2 taxation, energy efficiency and renewable energy policies have driven this change, and some of this can be attributed to an environmentally conscious culture in Sweden. Surprisingly, there is no official published policy on H2 by the Swedish government. Vatgas Sweden is a public-private partnership that provides leadership in H2 research and policy development, with many other research groups active in H2 developments, with several regional authorities active also in EU-funded H2 projects with pilot implementations.

2.2.7 UK

In the ten-point plan for a "Green Industrial Revolution" [19] of the UK government, the role of hydrogen is clearly identified: "….The UK already has world-leading electrolyser companies, and unparalleled carbon capture and storage sites that we can maximise. Working with industry the UK is aiming for 5GW of low carbon hydrogen production capacity by 2030. Hubs where renewable energy, CCUS and hydrogen congregate will put our industrial 'SuperPlaces' at the forefront of technological development. We are also pioneering hydrogen heating trials, starting with a Hydrogen Neighbourhood and scaling up to a potential Hydrogen Town before the end of this decade. Working alongside partners in industry, our aim is for the UK to develop 5GW of low carbon hydrogen production capacity by 2030 that could see the UK benefit from around 8,000 jobs across our industrial

[15] https://www.regjeringen.no/en/aktuelt/white-paper-on-norways-energy-policy-power-for-change/id2484248/#:~:text=Today%2C%20the%20Norwegian%20government%20presented,and%20climate%20friendly%20energy%20supply

[16] https://www.regjeringen.no/contentassets/8ffd54808d7e42e8bce81340b13b6b7d/regjeringens-hydrogenstrategi.pdf

[17] https://www.iea.org/news/sweden-is-a-leader-in-the-energy-transition-according-to-latest-iea-country-review

[18] https://sweden.se/nature/energy-use-in-sweden/

[19] The ten point plan for a green industrial revolution - GOV.UK (www.gov.uk)

heartlands and beyond. This will be supported by a range of measures, including a £240 million Net Zero Hydrogen Fund, and setting out next year, our hydrogen business models and a revenue mechanism for them to bring through private sector investment. The UK is already a world leader in investigating the use of hydrogen for heating, replacing fossil fuels like natural gas with hydrogen and hydrogen blends. We are keen to accelerate this work and support industry. For example, Ofgem will publish details later on the proposed network demonstration in the Levenmouth area of Fife, intended to provide hydrogen to 300 homes over a 4-year period…".

Notably, several hydrogen-related projects are funded across UK from investing heavily in the production of blue hydrogen (5GW production capacity) utilising carbon capture, usage and storage to the injection of hydrogen into the natural gas system (up to 25%), so that the overall carbon footprint of the use of natural gas is reduced. Worth noting is the slowly yet steadily increasing importance of "soft actions" recognised by all GH2 stakeholders.

The key issue of enabling GH2 in the UK is the availability of information to all relevant parties, coordination of various initiatives, resources necessary for the training of personnel, matchmaking, and technology assessment. Both the private sector and the government realise the need to maximise the interaction among all relevant parties, and thus the need for creating hubs/ accelerators at both the national and regional level. An excellent example of this is the Hydrogen Accelerator[20] at St. Andrews University funded by ERD.

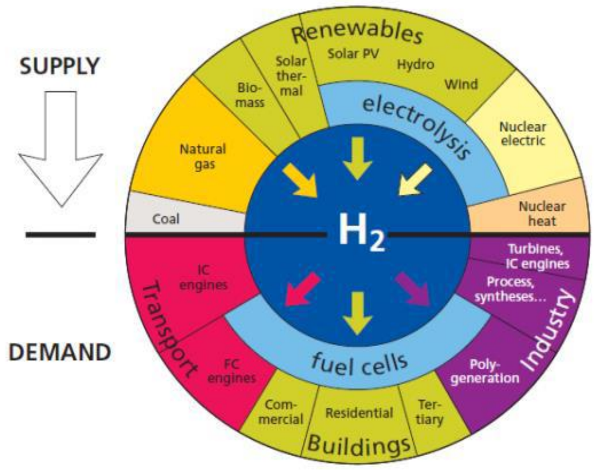
3.0 The emerging GH2 landscape

Across the NSR, governments have clear policies in place to reduce emissions to net zero by 2050. Significant reductions in the use of coal have helped to mitigate emissions from power generation in recent years, with total GHG emissions in the UK reduced by 57% compared to 1990 levels[21]. Governments throughout the NSR have recognised the potential of H2 as a low carbon energy vector. H2 is recognised has a key enabler to decarbonisation of heat and industrial operations. It is clear that urgent political determinations are required to make important strategic decisions on the future of existing infrastructure and the adoption of net-zero emissions technologies.

The entire North Sea Region faces the challenges of decarbonisation, energy security and availability of natural resources. GH2 can play a leading role in transporting, heating and powering the lives of the people and industry, while reducing environmental and societal impacts as well as putting forward the so called 'hydrogen economy', as depicted in the following Figure 1.

[20] https://h2-accelerator.wp.st-andrews.ac.uk/people
[21] https://www.instituteforgovernment.org.uk/explainers/net-zero-target

Figure 1. The Hydrogen economy



Theoretically, GH2 constitutes the perfect solution for clean energy needs. It is important to distinguish between green and blue hydrogen, as well as brown and black hydrogen: this is because hydrogen can be produced using four different processes. Green hydrogen, for one, is produced by electrolysis and when electricity used in the process comes from renewables; it is carbon free. Blue hydrogen is produced from natural gas, but carbon emissions are captured and stored or reused.

GH2 can be stored in large quantities for long periods, and it can be used as a fuel in virtually every sector of the NSR economy – from transport to industry to heating. To date, however, the potential of hydrogen has yet to be realised, though there have been several pilot projects, mainly in cities across the NSR. So, before GH2 becomes a reality in rural areas of the NSR, there are two complex issues to be addressed. Firstly, cost-effective, scalable and sustainable production methods need to reach mass market; thus, targeting investment towards reducing the high cost of producing large volumes of low carbon hydrogen is crucial. Secondly, a comprehensive and holistic approach is essential to determine the most appropriate application(s) of GH2 within a rural economy. This is because the various uses for green hydrogen are likely to be highly interrelated and this will have implications for the energy system of the community. In the face of these challenges, GH2 has the potential to decarbonise certain difficult sectors of the NSR economy. Even though there may never be the fully developed 'hydrogen economy' that some optimists have predicted, GH2 will still play a key role in enabling the energy transition, supporting the European 2030 and 2050 targets.

An NSR-competitive, sustainable and reliable energy infrastructure is required to meet the current and future needs of society and industry. To support Europe's transition to net zero by 2050, there is a need to invest in high-quality digital infrastructure and rapidly progress renewable and hydrogen projects. There should be enterprise support towards fuel switching, on-site generation and cost-effective solutions for industry. GH2 is an obvious energy vector that provides a truly sustainable and reliable holistic systems approach, requiring further exploration in rural areas.

3.1 GH2 potential in North Sea Region rural areas

Given the plentiful renewable resources stemming from wind and solar, there are hydrogen supply chain opportunities in rural locations that would complement the Hydrogen Roadmap for Europe, 2019[22] and to engage local supply chains in different sectors with the full range of hydrogen opportunities. Consideration of the wider opportunities for hydrogen is critical in engaging the rural supply chains and discovering specific capabilities which may exist across the regions' rural areas, as well as providing the prospects to protect current manufacturing and engineering businesses, post-COVID-19, through job creation and new employment preparation. If this is not done, there is a risk the supply chain will not see sufficient opportunity for development.

3.1.1 Early GH2 developments in North Sea Region rural areas

Wastewater Treatment Plants are normally situated in urban and rural locations and there are several concepts available to help kick start the hydrogen economy in the region. Oxygenation of these plants through the use of electrolysis can support the efficiency of the said plants, in addition to producing GH2 as a by-product and reducing costs considerably. Electrolysis can help to increase processing capacity, reduce carbon emissions and improve flexibility in the electricity grid, as hydrogen acts as a balancer to the electricity grid. The development of GH2 production and oxygenation will provide more efficient rural wastewater treatment plants allowing additional sewage to be added, hence saving on major infrastructure costs.

The potential applications of GH2 for the decarbonisation of energy in NSR rural areas are wide-ranging, with opportunities for use in heat, industrial energy demand, energy storage, as well as transport. Currently transport applications represent the highest value markets, due to the relatively high price of current transport fuels compared to natural gas, which currently functions as the main fuel for heat and industrial applications. To quantify the opportunity for potential GH2 suppliers, the business case for a GH2 production plant in NSR sites must be considered. This must be based on a deliberately conservative level of demand growth initially, in order to define the case for investment in the GH2 infrastructure that will be the backbone of the facility – naturally, built-out contingency should be factored also. Vehicle types such as haulage trucks ships and trains have great potential to increase GH2 demand in the NSR within the next decade. Indeed, GH2 appears to be the only credible option for fully decarbonising these vehicle types in many cases.

[22] Hydrogen roadmap Europe - Publications Office of the EU (europa.eu)

3.2 Pathways to GH2 in North Sea Region rural areas

There are several pathways to the production and utilisation of GH2 in rural areas across the North Sea Region, with each scenario requiring careful consideration, as a "one size fits all" approach is not feasible. Future smart regions, agricultural farms, industrial parks and everything in between must begin the process of decarbonisation. Reducing energy demand by generating all the electricity through solar is one achievable system concept for a net-zero energy smart region. However, not every moment is "zero energy"; for example, in the summer months, it is likely that more electricity is produced than consumed from solar, and in the winter the converse is probably true to say nothing of energy consumed in the transportation sector.

In a fully sustainable, smart energy system, a balanced electricity system can be achieved with electric batteries for day/night balancing and green hydrogen for seasonal balancing. During the summer, excess electricity can be converted into hydrogen by installing an electrolyser. In the winter, a fuel cell could supply electricity by converting hydrogen into electricity. Given the abovementioned hypothesis, there is a need for additional renewable energy for powering and balancing, and that energy could be supplied to the smart rural areas as hydrogen produced from wind, biomass or large-scale solar, essentially a holistic system approach.

Rural areas across the NSR finds itself in a relatively good position in terms of renewable energy production, especially given the availability of land that can house renewable energies – primarily solar and wind.

3.2.1 Power 2 Gas (P-2-X)

Given there is a clear desire to increase the amount of renewable energy across the EU's electricity system, power-to-gas (P2G), or Power-2-X (P-2-X), provides an alternative means of utilising excess renewable generation at times of low demand. This is done through electrolysis to create hydrogen and thereby acts as energy storage. P-2-X is used in a range of applications from industrial processes to acting as a fuel itself and could provide a solution to the curtailment issue of wind in certain NSR locations, thus unlocking even greater provision for the installation of renewables into the EU's electricity network.

GH2 produced through P-2-X can be considered as an energy carrier and has several distinct advantages as a form of storage over electrical batteries (e.g., greater energy density) and is therefore superior for several applications, including powering HGVs and other heavy mass transportation vehicles (e.g., rural agricultural vehicles). It can potentially be transported within existing gas networks through gas enrichment, albeit this is contingent on varying other factors, such as the percentage injection into either the gas transmission or distribution pipelines. GH2 can be converted into electricity using a fuel cell or burned directly in hydrogen applications such as thermal boilers – all of which would reduce greenhouse gas emissions and increase economic recovery through job creation and maintenance.

Currently, the price of producing green hydrogen through a combination of renewable resources and electrolysis is higher than that of reforming natural gas (being €3.50/kg of hydrogen vs €1.50/kg of hydrogen respectively), according to IEA[23]. The two main cost elements are: (i) The cost of electrolysis itself due to limited global penetration though this is forecast to fall by 70% in the next 10 years; (ii) The price of electricity from renewables, which is also expected to fall considerably to 2030. Notably, some commentaries suggest cost parity between grey hydrogen and green hydrogen by 2030, though indeed, policy drivers and R&D investment may accelerate this.

3.2.2 Curtailment of Wind

There requires a shift in focus towards the curtailment of wind when designing energy policy across the NSR and Europe. Too much intermittent generation on the grid may require the system operator to curtail devices such as onshore wind. Investment in non-intermittent renewables technologies, which are dispatchable and contribute to baseload electricity, should be considered as part of taking pressure off the network. This being said, non-intermittent renewables technologies have far more expensive costs/kWh. System operators have facilitated higher levels of renewable energy and supported in resolving curtailment issues by diverting the curtailed electricity into heat or energy able to be stored in batteries or used to generate hydrogen – but to date, this is not done at scale.

Distributed or co-location P-2-X projects where multiple renewable energy technologies and/or energy storage dynamically share a single grid connection are viewed as a means to maximising the contribution of intermittent renewables such as wind and solar energy. This is particularly important in rural NSR settings given the current limitations in available grid capacity and concern over increasing curtailment and constraint levels. The distributed P-2-X model should be considered for a number of reasons – particularly, as it will increase investor confidence to the EU energy system as a whole.

3.3 Current research activities

Investing in science and talent is a key priority for the EU, championing science as a key part of its Green Deal[24] agenda with scientists tackling the policy challenges and setting out the priorities for science, research and innovations of the coming decades. Innovation in technology, systems and products, will be crucial to the development of the green hydrogen economy in NSR regions. New and better conversion, storage, transportation and distribution technologies will be necessary for green

[23] https://www.iea.org/newsroom/news/2019/april/the-clean-hydrogen-future-has-already-begun.html
[24] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

hydrogen. The application of GH2 in industrial processes, materials, products and mobility (by land, water and air) is being developed further globally. Various related technologies and systems – such as sensor technology, safety control, fuelling systems, compression technology, smart ICT systems, smart regions, Internet of Things, and so on – are also progressing. Innovation should not just be viewed from a technological perspective; one should consider innovative business models, safety procedures, social acceptance, regulatory framework and procedures to be equally relevant.

There is already well-established infrastructure in place for research, education, training innovation and start-ups across the NSR, which will enable rural areas to play a leading role in applying the crucial innovations for a GH2 economy. Indeed, there is even potential for the NSR to be global leaders in many respects.

GH2's greatest strengths lie in the functions that it can fulfil within the system, such as providing flexibility, transport large quantities of energy (electricity in the form of GH2), and storage. These are high-tech functions that will demand high-tech controls, which means that the digital tech research and development is an indispensable link. Technological applications like dynamic pressure regulation and better modelling and optimising of gas distribution networks will be critical to introducing GH2 in the built environment and for movement through a hydrogen network or an existing gas network.

In conclusion, the aforementioned research and development activities (at lower TRLs) for the longer-term GH2 solutions that are deemed to be important for going into 2030 and beyond, and/or the robust elements for achieving the energy transition approaching 2050. These activities and several pilot projects across rural NSR settings should be oriented towards removing impediments and creating the right conditions for the development and upscaling of GH2 technology.

As observed thus far, themes that can play a role in the development of a GH2 economy in rural NSR areas include information campaigns, the human capital agenda, tech applications, embedding in the rural regions, and cross-border and transnational partnerships. This is probably the only way for the NSR to successfully achieve the ambitions of the Member States in the coming years and to ensure GH2 is sustainable.

4.0 Impacts and implications of GH2

4.1 Technological impacts

Rural North Sea regions must take advantage of the global interest in developing a robust GH2 niche market capable of developing novel electrolysers (with hundreds of MW) using the European value chain. Three main types of electrolysis technologies have been recognised in the global market as current or potential products, each named after the electrolyte type: alkaline electrolysis (AE) (liquid electrolyte), proton exchange membrane (PEM) electrolysis and solid oxide electrolysis cell (SOE).

Different modules, suitable for balancing power management (electricity and heat), water, H2 and O2 flows with energy consumption at nominal power levels have been manufactured[25,26]. There is a fourth option also – that of the membrane free electrolyser[27]. In this context, there is an opportunity for the NSR to couple GH2 ambition with Advanced Manufacturing Innovations, as this would create capabilities in a range of design and production, including factory automation, robotics and Industry 4.0 technologies (e.g., the digital twin to allow virtual testing of rural areas). These technologies form the underpinning foundation for the industrialisation of hydrogen products and would also require input from specialist disciplines.

It is very important to reduce the NSR's carbon footprint by at least 30% with the support of larger modules as well as the higher current densities. Hence, a clear roadmap in this direction would succeed in reducing electrolyser CAPEX by 20% down to €480/kW and €700/kW for alkaline and PEM electrolysers respectively, meeting the Fuel Cells and Hydrogen Joint Undertaking targets for 2024[28]. Certainly, one would expect an increase the stack lifetime with a degradation target (i.e., minimum nominal energy consumption at end of life) of 0.12%/1000 hours for alkaline and 0.19%/1000 hours for PEM[29].

4.2 Operational, social and environmental impacts

The North Sea Region is currently demonstrating the feasible operation of electrolysis and the use of GH2 in various applications valorising the renewable aspect of the produced hydrogen. Such opportunities allow for assessment and operational experience – including safety – of the contractual and hardware arrangements required to distribute and supply hydrogen to the specific industrial and/or transport markets, but not at scale. Additionally, assessment of the feasibility to connect the electrolyser to a production site of renewable sources of energy such as offshore/onshore wind, or solar plants at scale is also required. It is therefore important to consider the technical assessment of the suitability of the electrolyser equipment to operate in its expected environment and suggestion of best practices. Hence, the evaluation of the environmental performance of the system (in alignment with RED II compliant methodologies[30]), with attention to the CO_2 intensity of the hydrogen produced versus the natural gas route. Of utmost interest is also developing an understanding of the CO_2 impact of the grid services mode selected as well CO_2 footprint impact in the addressed hydrogen end-user markets.

[25] http://www.cres.gr/kape/publications/papers/dimosieyseis/ydrogen/A%20REVIEW%20ON%20WATER%20ELECTROLYSIS.pdf
[26] https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf
[27] https://www.cph2.com/
[28] https://www.fch.europa.eu/soa-and-targets
[29] https://www.goldmansachs.com/insights/pages/gs-research/green-hydrogen/report.pdf
[30] https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

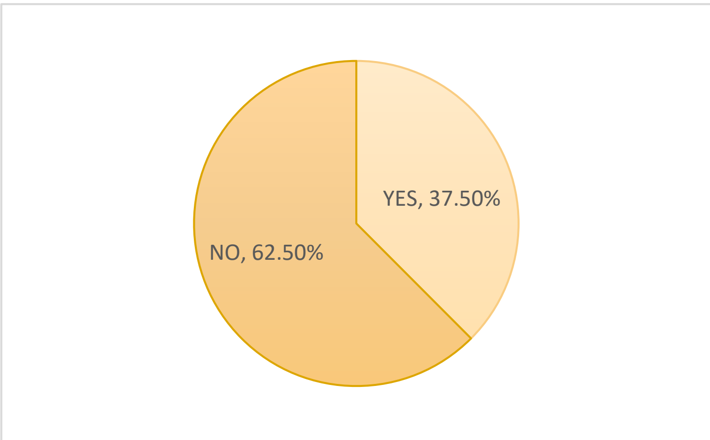
The demonstration of compelling economic and environmental cases, including boundary conditions, for key GH2 applications such as transport, energy storage, raw materials (hydrogen and oxygen) or heat and power production appear to be a priority in green hydrogen production acceleration. It is worth proving that Levelised Cost of Energy (LCOE) of up to €40/MWh (renewable sources), can achieve a significant cost reduction of GH2 striving for below €3 /kg and aiming for further reductions, possibly also by generating income from the provision of services to the electricity grid (e.g., balancing or frequency services).

4.3 GH2 labour market

Employment in the green energy sectors varies according to the type of renewable energy in which the employer is engaged. Recent developments in the GH2 sector present a more challenging future outlook for the GH2 industry than was predicted in 2011. Recent scenarios reflect shifts away from activities, such as planning and development, and shifts towards more maintenance-oriented functions. This is a feature of the future maturation of the industry and, crucially, also marks a transition to more permanent jobs, which are sustained by the requirement to supply renewable electricity, rather than jobs that depend on continued construction. In this context, more of the industry's future jobs will be long-term, rather than short-term, by nature. While the sector has a steady growth, policy support is critical to ensure that this continues at pace in the coming decade.

A survey carried in the context of this study sought several questions related to NSR employment market needs in the energy and decarbonisation transition. Interestingly enough, the HyTrEc2 project's sample consisted of 35% enterprises which had already been involved in the GH2 and GH2-related sectors.

Figure 2. Does your company already offer a service in the hydrogen or fuel cell field?



The interests of these surveyed companies cover the full spectrum of hydrogen and fuel cell fields is clearly indicated in Table 1 below.

Table 1. GH2 and fuel cell sector of interest

H2 and Fuel Cell sector of interest	
GH2 Production and Distribution, GH2 Storage	56.25%
GH2 Production and Distribution, GH2 Storage, Fuel Cell Applications, Other	31.25
GH2 Production and Distribution, GH2 Storage, Other	6.25%
GH2 Storage, Fuel Cell Applications	6.25%
GH2 Storage, Fuel Cell Applications, Other	6.25%

4.3 Skills needs and challenges

Although the days of traditional heavy engineering manufacture are mainly over, the engineering sector can look toward an optimistic future and provide substantial opportunities for people to have rewarding and interesting careers in an industry that is essential to the EU's economy. However, it must be emphasised that there has been a lack of obvious government focus in certain Member States that recognises the importance of the engineering and in particular manufacturing sector to the NSR's current and future economic success.

Manufacturing and engineering essentially underpin the success of key EU priority sectors as set out by the Green Deal agenda. The manufacturing and engineering sector is a skills-intensive business, reliant on a diverse range of occupations and a maintainable supply of professional, technical and operator skills to service the sector's needs.

Currently within segments of the manufacturing and engineering sectors, demand for skills is greater than supply across the NSR. Consideration must be given with respect to recruitment and training programmes as they can be difficult to manage and hard to slow down, so a careful approach is required with intervention, as skills shortage could quickly turn to a surplus. Skills shortages are evident today in manufacturing and engineering sectors across the NSR with employers choosing to manage the situation by competing for staff within the sector and recruiting only from industry supply chains, which does not add capacity and is not sustainable.

Realising present and potential future growth opportunities, such as those foreseen in the development of the hydrogen economy, will require the manufacturing engineering and construction sectors to overcome some significant challenges now and in the future. All sectors of the NSR economy face major skill challenges as the nature of work alters, global competition intensifies and the present workforce ages. The manufacturing and engineering sectors depend on a range of skills relating to Science, Technology, Engineering & Mathematics (STEM). Significant investment to ensure that the right people with the right skills are in place is critical to productivity, competency and innovation, and the scaling of GH2 production. The pace of change is likely to be particularly rapid within the engineering industry with development of new production processes based on Research & Development outcomes. Future skills needs for emerging technologies, advanced manufacturing and the low carbon, renewable energy supply chains is radically changing both the scope and scale of manufacturing, which will impact on the skills required.

4.4 Grounds for skills development

The North Sea Region faces a range of challenges in the realm of GH2 skills development, many of which are not new; namely, skills shortages, infrastructure deficit, digitisation, climate emergency, an aging population, and low levels of innovation in some rural areas of the NSR. When these challenges occur simultaneously, they can result in lower levels of competitiveness, economic growth and standards of living for the rural population. In a post-COVID-19 North Sea Region, opportunities will exist to rectify the aforementioned challenges and set in place measures that will address challenges, especially that of the climate emergency and skills requirement.

Skills are the key to shaping a better future and central to the capacity of rural regions in the NSR to thrive in the post-COVID-19 era. The technological advances in GH2 and demographic change have the powerful potential to reshape work and society, generating a growing demand for higher levels and new sets of skills. It is apparent that assessing the NSR rural regions' skills challenges and opportunities for building more effective skills systems depends on the development of policy responses that are tailored to specific skills needs. The foundation of this approach is the OECD Skills Strategy Framework, which allows for an exploration of what countries can do better to:

1) Develop relevant skills over the life course;
2) Use skills effectively in work and in society;
3) Strengthen the governance of the skills system.

This study has identified opportunities and makes recommendations to reduce skills imbalances, create a culture of lifelong learning, transform workplaces to make better use of skills, and strengthen the governance of skills policies across rural areas of the NSR.

With the COVID-19 pandemic, there will likely be a decrease of performance across industries. While the public health crisis requires the most immediate policy focus, multiple policy responses have been and will be required to provide immediate support to those affected by the pandemic, as well as to promote rural economic recovery strategies. Skills policies are an essential component and a positive exit strategy, but this requires careful investigation of the skills system holistically as well. Tackling climate change will require decisive global action and significant investment and innovation by the public and private sectors in line with the Paris Agreement and subsequent COP26 deals.

Meeting the ambitious net zero targets in rural NSR regions will create whole new industries, technologies and professions, and as such skills requirements need due consideration. There have been large investments and growth of the NSR offshore wind manufacturing infrastructure recently, creating jobs and opportunities in the offshore wind supply chains. Similar investments across a range of low carbon emerging sectors have also been observed. With the transition to a net-zero carbon economy, skills agencies and funds should be considered for rural areas in support of the imminent changes. Companies are not always fully aware of the scope of the transition to a net-zero carbon economy and do not always clearly articulate their skills needs. Therefore, educational and training providers should be involved in the work of skills development systems in order provide their insights. The involvement of professionals and experts working in the private sector is essential in delivering the essential learning opportunities. Educational and training providers' capacity and the quality of training programmes are not always adequate and the availability of qualified teachers with relevant low carbon knowledge is scarce. In Germany, for example, some inter-company vocational training centres (e.g., Überbetriebliche Bildungszentren) develop and provide new advanced green skills programmes to companies, in particular SMEs (European Commission, 2018[31]). Furthermore, the partnerships between education and training providers and private sector could be beneficial in reducing the cost of training for companies in transferable and expensive to develop skills, particularly when considering advanced skills and apprenticeships.

Indeed, despite this high cost of training for companies, subsidies and incentives targeting the private sector are not present. This presents an opportunity for collaborative working with educational, training providers and private sector companies to share technological resources, as well as knowledge, to improve the skills output and to reduce cost of delivery.

4.5 GH2 skills gaps

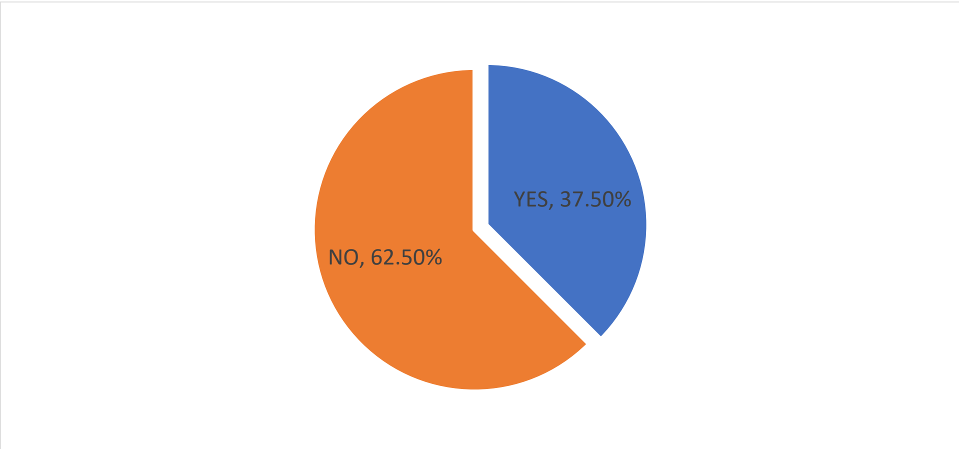
Educational and training institutions need to adopt effective skills anticipation systems, providing accurate and real-time labour market intelligence[32]. Often companies are not capable to articulate their skills needs (for example, in relation to green skills); hence, VET providers must take the lead in skills development systems to be capable to provide those skills at the time industry realises this

[31] https://ec.europa.eu/esf/transnationality/TCA-1523
[32] https://www.cedefop.europa.eu/files/3069_en.pdf

demand[33]. The manufacturing engineering sector is faced with a strategic challenge arising from the industry's changing skills needs. Today, skills gaps are increasing for a number of reasons. For example, there is a view that the training of recent recruits has narrowed, especially in STEM-related areas. Skills gaps are not easy to overcome by recruitment alone; they should be addressed by industry itself in collaboration with educational and training providers, industry lead programmes with more transition training from other sectors is essential. In the survey of the present data, the Interreg NSR HyTrEc2 project obtained the following training needs across participating companies.

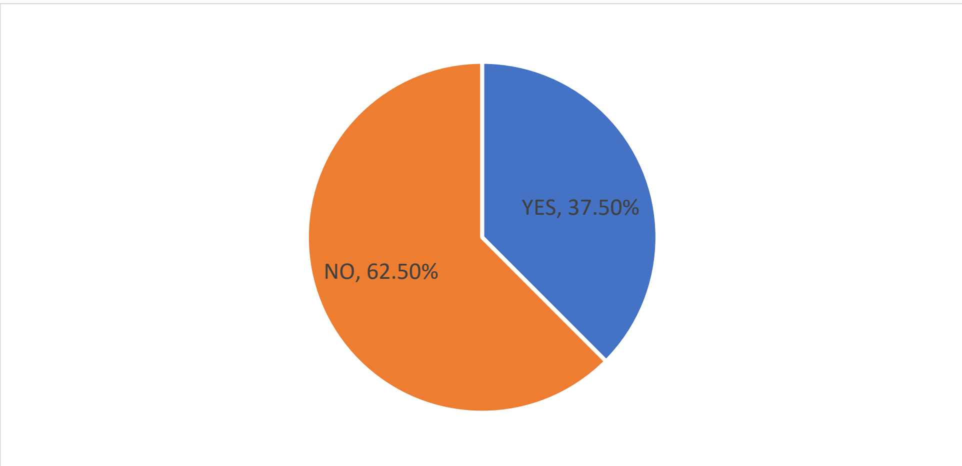
The survey conducted within the scope of this study showed that 62.5% of the participants reported a difficulty in finding specialised personnel.

Figure 3. Is it easy to find qualified/ skilled professionals operatives?



Notably, this rather surprising result indicated that 62.5% of the companies reported having difficulties finding specialised personnel do not cooperate with educational training centres.

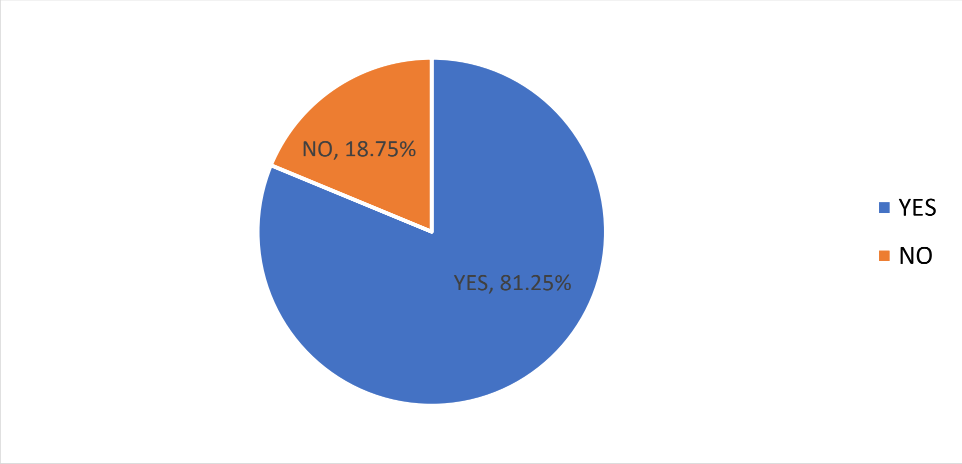
Figure 4 . Does the company have any cooperation with educational /training centres?



[33] https://www.gatsby.org.uk/uploads/education/the-opportunities-for-learning-factories-in-the-uk.pdf

Given that there is a lack of qualified personnel in the Industry 4.0 manufacturing sector, it is not surprising that the majority of companies (81.75%), have to train their workers in order to meet their operation needs. This training often comes at a great cost to the employer, frequently having to send employees to the other NSR and EU regions or further afield.

Figure 5. Does the company need to train workers for hydrogen or fuel cell activities?



As Table 2 illustrates, companies rely on different kinds of training, both internal and external.

Table 2. Kinds of training provided by companies.

Internal training	81.80%
Short professional training	81.8%
Short theoretical courses	72.70%
Long undergraduate programs at Universities	18.20%
Long courses at training centres	54.50%

In terms of aspects of training, regulatory/security aspects appear to be the most important for the development of a knowledgeable workforce in NSR.

Table 3. Aspects of training

Technical aspects	78.60%
Regulatory/ security aspects	92.90%
Asset management	7.1%

The most surprising result seems to be the answer to the question: Who should be trained? All companies surveyed believe that engineers require training.

Table 4. Who should be trained for hydrogen or fuel cell related activities?

Technicians	69.20%
Engineers	100.00%
Academics	15.40%

GH2 is gaining traction with the potential to represent a key pillar in the delivery of the net zero-emission targets by addressing the issues of the big three energy consumers – namely, electricity, heat and transportation. Delivering the net zero targets across the NSR will require the rapid deployment of Electrolysers, smart District Heating Systems, Smart Control and Electric/Fuel Cell Vehicles.

Equally important, however, is training and skills development in a workforce that will be asked to support the NSR's decarbonisation and smart manufacturing using advanced knowledge technologies. More importantly, the use of GH2 in the NSR's decarbonisation will require advanced standards to be applied at the workplace. The survey raises the question if VET/HEI are delivering the specific skill sets that are demanded by the emerging industries that are being driven by policy and need for post COVID-19 recovery.

5.0 Drivers and constraints to technology adoption and innovation

The recent accomplishments of solar PV, wind, batteries and electric vehicles have shown that policy and technology innovation have the clout to build green energy industries. Nowadays, policy makers and industrial technologies have tapped GH2's potential to play a key role in the NSR's clean, secure and affordable energy future. As it has been repeatedly reported in the press and in research, GH2 can help us deal with the recent critical energy challenges concerning climate change mitigation, as well as in the decarbonisation of several sectors (e.g., transport, industry), improvement of air quality and strengthening of energy security. GH2 can become the enabler for use of energy in new ways, including production, storage, and transport. As a result, GH2 has attracted the interest of the Member State governments as well as renewable electricity suppliers, industrial gas producers, electricity and gas utilities, major engineering firms and cities and towns across the entire NSR. This interest has stimulated investments in green hydrogen and has reinforced new technological and industrial development in national, regional and local economies, creating skilled jobs.

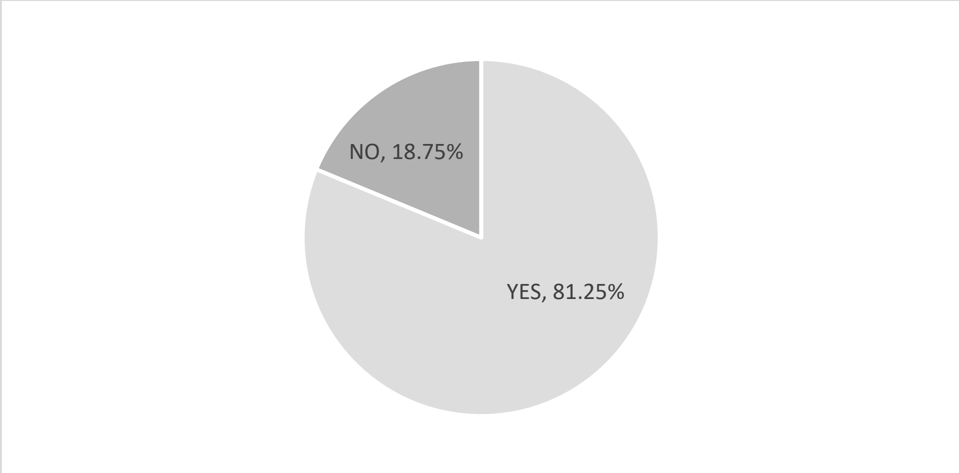
Fuel cells, refuelling equipment, and electrolysers (which produce green hydrogen from electricity and water) can all benefit from mass manufacturing. However, the development of GH2 infrastructure is slow and holding back widespread adoption due to the fact that GH2 prices for consumers remain highly dependent on several parameters, such as the number of established refuelling stations, the frequency of their daily use and the amount of GH2 delivered daily to them. Tackling the above requires planning and coordination with the governments, the industry and the investors working together on finding solutions. Notably, the current regulatory frameworks in place across regions limit the development of the GH2 industry. National and regional governments and industry must work together to limit the barriers to investments, to provide investors with incentives, and to take into consideration international standards for the safety of transporting and storing large volumes of green hydrogen – in addition to tracing the environmental impacts of different green hydrogen supplies.

The importance of an unhampered flow of information among all stakeholders in high-tech sectors, such as GH2 and fuel cells, cannot be overstated. Given the riskiness of the projects in such industries, available expert human resources must be utilised, all opportunities are to be exploited, and successes and failures must be become readily known. We often come across the paradox of the industry moving forward, while neither the cooperation among stakeholders, nor the availability of knowledgeable workforce members can be seen.

This paradoxical phenomenon is also observed in the educational and vocational training programmes following industrial innovations, but capability is sporadic at best. One would expect that industry would seek working closely with the educational and training institutions to ensure that employees are prepared to work with new technologies and services, and that knowledge and technology transfer networks are capable of supporting an exchange of information among stakeholders.

In a survey that was conducted among relevant participants within the HyTrEc2 project, it was found that the majority of the participating industrial firms collaborate with others, as it is shown in the following figures, Figure 6 and Table 5.

Figure 6. Does your company have any collaboration with other companies in this field?



For the firms that collaborate with other firms, approximately one-third keeps this collaboration at the regional level (i.e., a considerable amount), and the rest go nationally and or internationally.

*Table 5. If your firm does have some form of collaboration in this field, at which level?**

Regional	**38.46%**
National	23.08%
International	38.46%

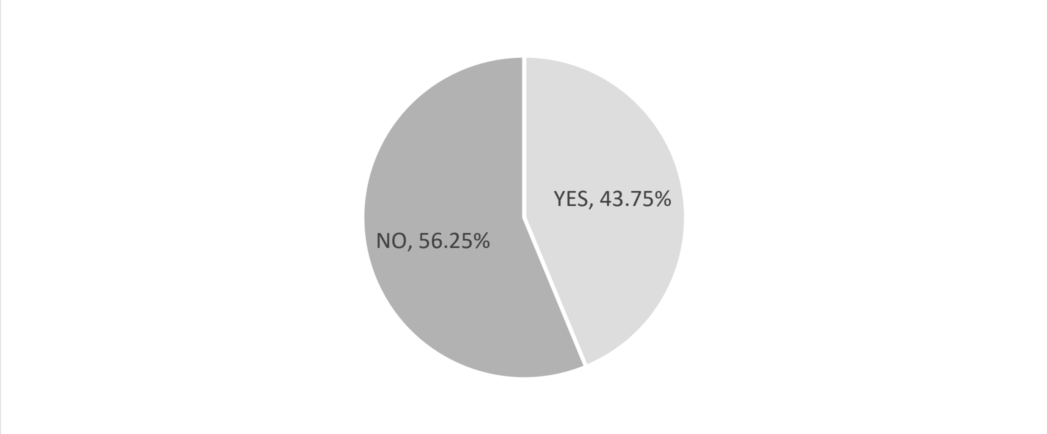
*National includes regional; international includes national.

Interestingly enough, 56.25% of the firms participating in the survey reported that they do not collaborate with universities or VET, as indicated in the following Figure 7. Several explanations can be offered for this, with the most likely one being that there is a rift between the academic/training ecosystem and the GH2 industry. This is very likely to be true, even despite the important role of decarbonisation in industry has been initiated by research and development in university laboratories even several decades ago.

The interaction and collaboration between these parties has become a central concern in applied economics[34] and has influenced recent economic policies. A firm's ability to identify, acquire and utilise external ideas to understand how its operations play a role in, or are connected, to industry is a critical factor in achieving market success.

[34] Arvanitis, S., Sydow, N., Woerter, M. (2008). Is there any impact of University-Industry knowledge transfer on innovation and productivity? An empirical analysis based on Swiss firm data. Review of industrial organization, vol. 32, no. 2, pp 77-94.

Figure 7. Does your firm have any collaboration with universities?



5.1 Science and technology policies

Science and technology policy is regarded as an essential factor for future growth across the entire NSR, but particular attention should be paid to rural areas. Within this study, the implications of the science and technology policy will be discussed in the context of building ecosystems through complementarity industries, solving social problems through science and technology, strengthening SMEs' participation, and sharing knowledge and strengthening cooperation among all members of the value chain.

Public funding will enable research institutes and universities throughout the NSR to have access to better lab equipment and digital resources, and to improve and maintain current research facilities. It is clear that EU policy complemented by ambitious national and regional plans also supports efforts to address several global challenges, such as climate change mitigation by 2050, and to improve life at home by strengthening national security and improving public services.

5.2 Industry 4.0

Industry 4.0, often referred to as the Fourth Industrial Revolution, encompasses a wide variety of technological advances across the entire value-chain. Industry 4.0 technologies and processes include the following, automation through digitisation and robotics, Internet of Things (IOT), Artificial Intelligence (AI), additive manufacturing, etc. All these innovative technologies and processes are revolutionising traditional manufacturing and engineering processes. As a result of increased use of digital technologies, the boundary between the real and the virtual world is increasingly narrowing, embarking into what is sometimes referred to as cyber-physical production systems. Industry 4.0 is transforming production value chains and business models into digital supply networks and has the ability to transform how we see rural areas from an industry perspective. Digital supply networks are dynamic and integrated, allowing faster and real time decision making, for example in the areas of predictive maintenance, quality management and demand forecasting.

The so-called “smart factory” for clean technologies can self-optimise performance by self-adapting to and learn from new conditions, autonomously running entire production processes. Its solutions can be applied across the manufacturing and engineering value chains, making processes more efficient, but companies will require support in doing this. The creations of more personalised, diversified, and mass-produced products require new skills development or reskilling. It is, therefore, critical that companies prepare their employees for these changes through appropriate training and continuing education. In other words, Industry 4.0 manufacturing infrastructure requires new recruitment and talent attraction strategies as well as continuous technical and operational skill development. The above is stated, as it is evident the GH2 production shall be enabled by digital technologies and skills. The survey carried in the context of this study has indicated that the 35-44 age redistribution is notably biased, as it is shown in Table 6 below.

Table 6. Within your organisation, towards which age range is the age redistribution biased? (Associations of employers and companies)

Age range	%
25 -34	11.76%
35 - 44	70.59%
45 - 64	5.88%
Evenly shared	11.76%

This age bias becomes more complex under the intensive revisions and upgrades needed to keep up with the high volume of production challenges; these challenges are introduced by decarbonisation interventions in several sectors and the use of GH2.

Industrial manufacturing 4.0 is transforming not only the industrial production but also society as a whole. Over the years, we have noticed a shift from steam power and mechanical production, to mass production and assembly lines, to IT, Big Data Analytics and the Internet of Things (IoT).

Figure 8 below presents the specific interest of SMEs for (Industry 4.0) transition and strategic development training programmes.

Figure 8. The manufacturing sector is moving towards Industry 4.0 at a time when a significant share of the manufacturing / engineering current workforce is close to retirement. How would you structure training programmes to allow a smooth substitution of retiring workforce with young people? (Employers, Chambers of Commerce - CoC, other agencies)

VET providers, associations of employers and companies underline the need for balanced employer engagement, case-related (Industry 4.0) transition, and strategic development training programmes allowing a smooth substitution of the retiring workforce with young people for meeting 4.0 skills demand.

Table 7 indicates the growing need for training programmes in post-COVID 19 Industry 4.0 manufacturing addressing the application of an engineering skills manual, robotics engineering and engineering management. On a subsequent question, VET institutions and industrial SMEs maintained that there is a shortage of supply of Industry 4.0 skills, as it is shown in Figure 9. This result justifies the already delineated needs for training programmes that can be reached, as it is shown in preceding data information.

Figure 9. At national/regional/local level, what do you think about the supply vs demand of Industry 4.0 skills? (VET providers, associations of employers, companies)

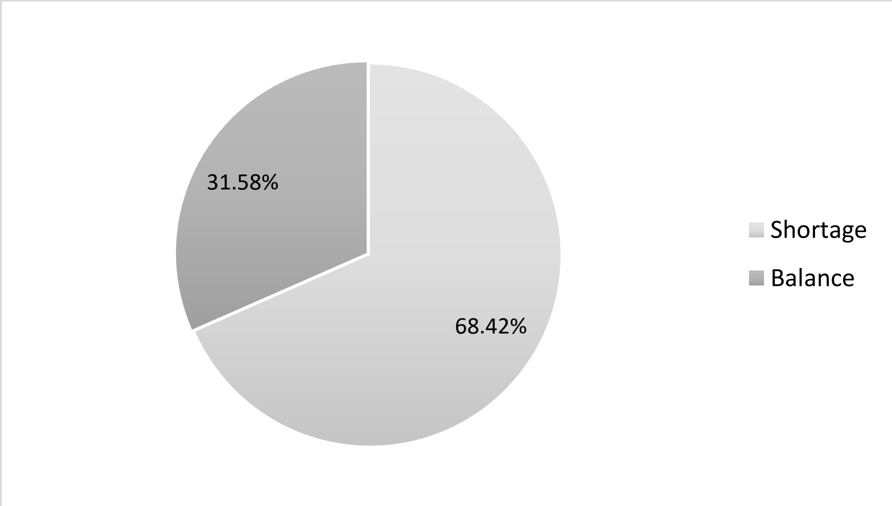


Table 7. In which fields/sectors do you expect the most severe skills shortage? (Associations of employers and companies)

Data analysis	10.52%
Data scientist	10.52%
Engineering hardware	5.26%
Engineering management	26.32%
Engineering networks	10.52%
Engineering skills manual	78.95%
Engineering software	10.52%
Quality engineer	5.26%
Robotics engineer	26.32%

The demand and supply of skills for Industry 4.0 and STEM skills appears to depend on enhancing attractiveness by increasing benefits and rewards. Meanwhile, a higher number of STEM graduates as well as better workforce planning seem to concern employers, as indicated in Table 8 below.

Table 8. If you expect shortage of Industry 4.0 skills and STEM skills at national/regional/local level, which strategies do you consider more suitable to reach a balance between demand and supply of skills? If possible, detail your answer. (Associations of employers and companies)

Better cooperation with VET providers	55.00%
Better workforce planning	50.00%
Encourage labour mobility	5.00%
Encourage the increase of female workforce	15.00%
Increase attractiveness by increasing benefits and rewards	55.00%
Increase focus on ICT basics - Outlook, Word, Excel. And also communication basics.	5.00%
Increase number of IOT/STEM graduates	30.00%
More practical hands on work in Secondary Education and beyond	5.00%

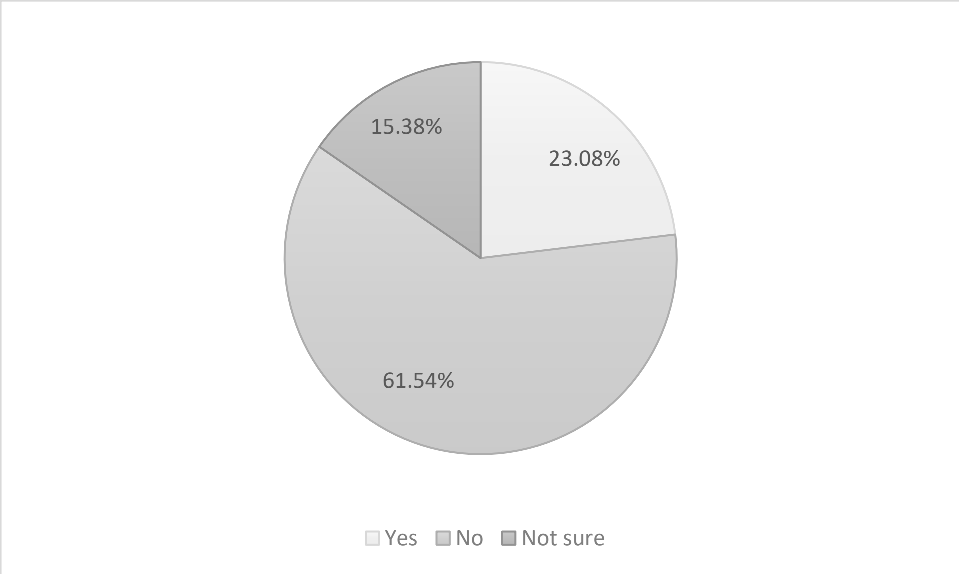
Furthermore, Table 9 below indicates that VET providers foresee an Industry 4.0 skills shortage that could be faced through the development of demand-led (employer-led) skills development programmes, better communication of career paths from an early age, and increasing attractiveness of related curricula.

Table 9. If you expect a shortage of Industry 4.0 skills and STEM skills national/regional/local level, which strategies do you consider more suitable to reach a balance between demand and supply of skills? If possible, detail your answer. (VET providers)

Apprenticeship opportunities within STEM jobs etc.	5.26%
Better communication of career path(s) from early age	63.16%
Demand-led (employer-led) skills development programme	73.68%
Encourage female workforce	5.26%
Increasing attractiveness of related curricula	42.11%
Labour Market Intelligence tools (e.g. skills anticipation systems)	15.80%

The next figure (Figure 10) shows that 61.54% of VET providers underline the importance of increasing their use of labour market intelligence tools.

Figure 10. Do you / are you going to increasingly use labour market intelligence tools, such as skills anticipation systems? (VET providers)



Notably, regional outcome agreements with chambers of commerce and business associations are supported by 55.56% of VET providers as depicted in Table 10.

Table 10. How would you structure a "demand-led" skills development system? How should the communication with companies be improved in terms of skills needs? (VET providers)

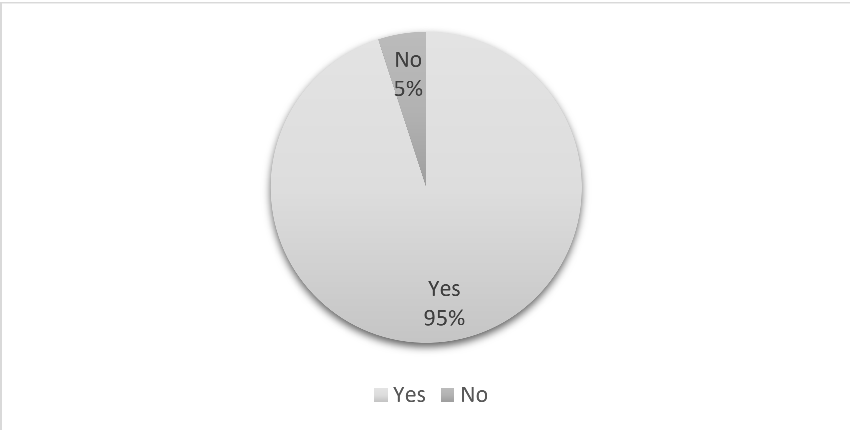
National agencies – top-down approach	33.33%
Regional outcome agreements with chambers of commerce – with all stakeholders.	55.56%
Skills focus programmes ran in conjunction with local industry	5.56%
Through College and Uni network	5.56%

Moreover, both VET providers and companies maintain that STEM training programmes will become more attractive to young people by: increasing benefits and rewards, improving links between VETs and other educational institutions, introducing STEM subjects earlier on in school, and providing role models for greater female participation in STEM (see Figure 11).

Table 11. How would you make STEM training programmes more attractive for young people? (VET providers and companies)

Allowing firsthand experience through work placements etc.	5.00%
Better communication	40.00%
Creating awareness of the opportunities available	5.00%
Increasing benefits and rewards	55.00%
Introduce better links between VETs and other educational places	50.00%
Introducing STEM subjects earlier in school	55.00%
Provide role models for greater female participation in STEM	50.00%

Figure 11. At national/regional/local level, do you consider there is a significant gender imbalance in manufacturing? If yes, which are the reasons behind this? (Associations of employers and companies)



Further, Table 12 suggests that VET providers and employers recommend that 4.0 manufacturing will become equally attractive to women by providing role models currently employed in Industry 4.0 manufacturing as well as related industry schools or VET collaboration programmes "taster courses".

Table 12. How would you make a career in smart manufacturing more attractive for a female workforce? (VET providers, associations of employers and companies)

Education on the range of job roles that exist	5.00%
Extra curricular activities, or competitive school courses	5.00%
Publicity campaigns	10.00%
Role models currently employed in related industry	75.00%
Schools / VET collaboration programmes "taster courses"	75.00%

As it is shown in Table 13, Industry 4.0 manufacturing employers report there are gaps in skills in AI/AR developers, app developers, Big Data analytics (data scientists), cobot engineers, cybersecurity, production process development and engineering (i.e., software, hardware, application, network).

Table 13. Considering the transition to industry 4.0 at national/regional/local level, what skills gaps exist in relation to an Industry 4.0 workforce today and in 5-10 years' time? (Associations of employers and companies)

AI/AR developers	35.00%
App developers	30.00%
Big data analytics (data scientists)	30.00%
Cobot engineers	35.00%
Cybersecurity	40.00%
Innovative Designers	5.00%
Microcontroller/CDS programmers	25.00%
Production process development	35.00%
Software, hardware, application, network – engineering	35.00%
Statisticians	15.00%

The following question elicited the opinion of VET institutions and industrial firms about the major reasons behind skills gaps in the Industry 4.0 workforce.

Their answers elucidate our understanding about the causes, which include, the fast technological changes, the lack of financial resources to upgrade curricula, the lack of reliable labour market intelligence, the lack of strategic direction, and the lack of workforce planning, as it is highlighted in Table 14 below. It is interesting that lack of capability and or resource from VET providers was marked low, this is in contrast to a similar question asked to employers.

Table 14. Which are the major reasons behind skills gaps in Industry 4.0 workforce? (VET providers, associations of employers and companies)

Fast technological changes	55.00%
Lack of agility from VET provision	20.00%
Lack of financial resources to upgrade curricula	45.00%
Lack of lifelong learning and commitment to staff development + predicting future gaps	5.00%
Lack of qualified trainers	30.00%
Lack of reliable labour market intelligence	15.00%
Lack of strategic direction	30.00%
Many people push students to go to university when they would be better to join a company sponsorship and earn instead of create student debt. Think we need to re brand not going to university, so that is not seen as a lesser option	5.00%
Only vocational colleges are offering exposure to industry relevant resources. Mainstream schools need to seek out relevant hardware/software to prepare students for HE programmes and job roles in Industry 4.0.	5.00%
Poor workforce planning	25.00%
Standardised learning programmes	10.00%

It is worth noting that workforce associations and SMEs would more likely hire new permanent staff already possessing 4.0 manufacturing skills, as designated in Table 15 below.

Table 15. At national/regional/local level, what are the strategies of SMEs and large companies to address skills gaps today and in 5-10 years' time? (Associations of employers and companies)

Automating the work tasks completely	15.00%
Collaborative arrangements with VETs	55.00%
Hiring freelancers and external contractors	25.00%
Hiring new permanent staff already possessing these skills	60.00%
Retraining existing employees	55.00%
Skills have to be used in order to be maintained, so retraining and working with educational providers would be best	5.00%

VET providers' responses have underlined the importance of developing demand-led skills training programmes and employer engagement programmes that involve curricula co-creation, innovative learning methods, increased quality of trainers, state-of-the-art IT-enabled resources and improved financial resources, as depicted in Table 16 below.

Table 16. At national/regional/local level, what are the strategies of VET providers to address skills gaps today and in 5-10 years' time? (VET providers)

Better quality of trainers	30.00%
Co-creation of curricula	30.00%
Demand led skills development programmes/ employer engagement programmes	75.00%
Improved financial resources	40.00%
Innovative learning methods	60.00%
Introduction of WBL modules	5.00%
Networking across the sector to work together to develop provision	5.00%
State-of-the-art IoT enabled resources	45.00%

In the conducted survey, VET providers have addressed the shortage of qualified trainers and the lack of financial resources for constantly updating training programmes and have mainly attributed this problem to the absence of commercial corporate training programmes, the need for improving training terms and conditions, and the lack of sharing resources training programmes, as it is depicted in Table 17 below.

Table 17. How could VET providers address the shortage of qualified trainers and the lack of financial resources for constantly updating training programmes? (VET providers)

Commercial/corporate training programmes	55.00%
Financial incentives for specialist trainers	5.00%
Improved terms and conditions	35.00%
Increased re-use of materials from large providers	5.00%
Refreshed programs every so often to keep up to date	5.00%
Shared resource training programmes	45.00%
Split courses into core principles modules and detailed add on modules.	5.00%

It is well known that companies often underestimate the impact of the green economy and "green skills" needs. VET training providers have clearly highlighted the importance of marketing campaigns and the demonstration of AI/ML/AR resources, as it is presented in Table 18 below.

Table 18. Companies often underestimate the impact of the green economy and their green skills needs. How would you increase their awareness? (VET providers)

Collaborative process	45.00%
Dedicated AI/ML/AR demonstration resource	30.00%
Marketing campaign	60.00%
New technological resources	20.00%
Worked examples tailored to the typical existing business models	5.00%

The survey has provided very important recommendations for addressing green skills shortage by communicating an improved attractiveness of new occupations, encouraging better cooperation with VET providers (e.g., demand-led skills development systems), introducing forward-looking workforce planning, and increasing the number of STEM graduates, as it is shown in Table 19 below.

Table 19. Which strategies would you adopt to tackle green skills shortage? (Association of employers and companies)

Better communication about potential growth of green occupations	36.84%
Better cooperation with VET providers (e.g. demand-led skills development systems)	52.63%
Clearer signals from public policy before investing in green skills	26.32%
Encourage labour mobility	10.53%
Encourage the increase of female workforce	21.05%
Forward-looking workforce planning	47.36%
Improve attractiveness of new occupations	57.89%
Increase attractiveness by increasing benefits and rewards	36.84%
Increase financial resources for training in transferable and expensive-to-develop STEM green skills	36.84%
Increase number of STEM graduates	42.11%
Increase the number of teachers with updated green knowledge	36.84%

VET providers have offered valuable strategies for tackling STEM green skills shortage that included: helping companies in expensive-to-develop STEM green skills training; and, improving the attractiveness of new occupations through structuring innovative curricula, linking STEM skills to green economy, as indicated in Table 20.

Table 20. Do you expect skills shortage with respect to STEM green skills at national/regional/local level? Which strategies would you adopt to tackle this? (VET providers)

Anticipating green transition before companies fully embrace the green economy, helping them in articulating their green skills needs (e.g., education led skills development programmes)	21.05%
Better communication about potential growth of green occupations	10.52%
Better communication of career path(s) from early age	21.05%
Encourage entrepreneurship	5.26%
Encourage female workforce	15.79
Helping companies in the implementation of training in transferable and expensive-to-develop STEM green skills	31.58%
Improve attractiveness of new occupations and curricula (e.g., waste management)	31.58%
Improve cooperation between recruitment and training (e.g., demand led skills development programmes),	26.32%
Increase awareness of companies about the possibility stemming from a green economy	15.79%
Structuring innovative curricula linking STEM skills to green economy	31.58

In conclusion, the global GH2 economy is estimated to be worth $2.5 trillion by 2050, supporting 30 million jobs. The NSR is creating a GH2 strategy, which includes plans for multibillion-Euro investment in GH2 projects and schemes to boost sales of products and services in energy sector. The upshot of this is a rapidly growing employment market, which requires skilled professionals to cover every part of what a highly technical industry is. As the manpower services provider of choice to many, VET institutions have a great potential to help companies with their delivery challenges. But like with industry, change is required.

5.3 Trade and investment

Supplying GH2 to industrial users will be a major business around the world over the next 10 years. Demand for green hydrogen has doubled since the early 2010s due to declining costs for renewable electricity, in particular from solar PV and wind. Most interest has been centred on electrolytic hydrogen as it is reported in recent demonstrations. Producing all of today's globally dedicated hydrogen output from electricity would result in an electricity demand of 3,600 TWh, which equates to more than the total annual electricity generation of the European Union. With declining costs for solar PV and wind generation, building electrolysers at locations with excellent renewable resource conditions constitute the low-cost supply option for GH2. It has been suggested that transmission and distribution costs of transporting green hydrogen from renewables locations to the end users is still the most appealing option.

In essence, GH2 has not yet met its potential to boost the clean energy transitions. Ambitious, targeted and near-term action is needed to further overcome barriers and to reduce costs. Notably, NSR rural areas have already four value chains that offer viable opportunities to scale up hydrogen supply and demand, building on existing industries, infrastructure and policies. These include: (i) The industry of natural gas and industrial production with the significant potential for emissions reductions from clean hydrogen; (ii) Transport with trucks, shipping and aviation seeking green hydrogen based fuels; (iii) The building stock and related natural gas networks blending green hydrogen, particularly in dense cities, with the prospect of direct use of hydrogen in hydrogen boilers or fuel cells; (iv) Power generation, in which green hydrogen is one of the leading options for storing renewable energy in rural locations and using it in gas turbines to increase power system flexibility. These chains require the support of a skilled workforce that will strengthen and ensure their growth.

6.0 Next steps and recommendations

GH2 technology is a relatively new area that has been tested on a small scale, although there are now some very significant GH2 developments across the NSR. Nonetheless, GH2 poses new technologies to be used in many applications, such as transport, the built environment, energy storage and flexible energy applications. As the conducted survey has shown, the time is now to pursue activities that are oriented towards the specific knowledge and expertise to make GH2 a major factor in the energy transition throughout the NSR over the coming years. This means that knowledge and expertise will have to be developed at all levels – that is, with employers and employees. These skills may relate to a broad spectrum of areas, such as working with high pressure gases, in the extreme cold, at stationary and mobile applications, and in a variety of environments (e.g., industry, built environment, transport, on- and offshore settings). Such required skills cover many areas, such as infrastructure, storage and technology applications, and draw on varying disciplines – from technology to economy to institutional affairs and social sectors.

The GH2 implementation is ambitious and will be deployed against the background of the enormous demand for qualified personnel in all the many areas involved in the energy transition. For this reason, there is also a need for a strong human capital agenda.

Moreover, conversion to a GH2 economy offers new economic prospects to many NSR rural areas for significant revenues. Energy models and simulations in the scientific literature reveal that the future GH2 needs (i.e., transport, industry and heating) increase significantly under decarbonisation scenarios through Europe. Such scenarios cover more sectors (e.g., heavy industry and buildings) where the role of GH2 can be crucial. From this perspective, decarbonisation with the use of GH2 is a no regret option and can pave the way to a future in which hydrogen is produced in a carbon-neutral way. There is a need for the development and implementation of a sustainable strategy for exploring, addressing and managing significant decarbonisation initiatives.

In light of the above, the following recommendations are worth considering for NSR rural areas:

1. The roadmap for the decarbonisation of NSR rural areas must be monitored by relevant indicators for building resilience of infrastructure, facing climate change risks, and applying inspection and monitoring initiatives.
2. Life-Cycle Management Plans need to be created in order to de-risk the NSR rural areas natural resources from climate change impacts in parallel with decarbonisation.
3. Increase stakeholder action in the natural environment and create Action Plans for several interventions that involve stakeholder engagement and the risk posed by inertia.
4. Develop a model for predicting its ongoing greening actions and assessing the impact of decarbonisation interventions in rural areas.
5. Identification and benchmarking of best practices for building a resilient rural environment of zero-carbon footprint.
6. Create synergies with agriculture organisations for delivering training programmes and evaluating new farming precision technologies as well as horticulture technologies to systemically reduce GHG emissions.
7. Support the development of programmes that harness skills training for meeting the employment market's needs in rural areas.
8. Establish an accelerator for supporting startups developing tech for the transition away from fossil fuels. The accelerator will grant them access to technical resources that can aid the testing, standardisation and commercialisation of their products and services. The accelerator will offer technical solutions in: (i) GH2 energy generation / electrolysis; GH2 based energy storage systems; (iii) Hydrogen Fuel Cells.
9. Phased implementation of P-2-X pilot project(s) unlocking a host of potential economic, environmental and societal opportunities.

In closing, meeting the EU targets for lowering CO_2 and/or GHG would definitely allow costs and benefits of decarbonisation to play an important role within rural locations with relevant skills development helping to mitigate economic and social shocks in the future and could help to prepare for challenges posed by megatrends, such as digitalisation and technological change, an ageing population, and climate change. A rural NSR GH2 niche market has a great potential to inspire start-ups to offer new innovations and solutions to a global problem. Many rural locations throughout the NSR are very well placed to capitalise on the opportunity offering, given the distributed renewable source assets. The creation of flexible P-2-X pilots will bring a wide range of opportunities through existing supply chains, support the NSR transition to a decarbonised energy future, and allow both existing local companies and new entrants to the market to prosper and develop, given new policy drivers and incentives. The availability of low-cost, GH2 and the creation of supply chain will unlock demand from transport and other applications across nSR rural regions, enabling public/private investment in infrastructure and facilitating the further development of local supply chains and expertise, including that of the skills requirements of the near future. In doing so a confident Covid-19 recover plan leading to a decarbonised NSR is possible.