ely4OFF

PEM ELECTROLYSERS FOR OPERATION WITH OFFGRID RENEWABLE INSTALLATIONS

RCS analysis at EU and international level

Deliverable 2.2

GRANT AGREEMENT
700359

D2.2 RCS analysis at EU and international level

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Executive Summary

The present study covers regulations at European level, to ensure all serve to achieve the quality and safety of equipment, materials, and processes. In a first approach, state of art regarding off-grid projects in Europe has been researched. It has been also identified some specific national requirements in four different countries where off-grid applications are envisioned to be related to niche markets, in order to take a first step in improving and overcoming the main barriers to the hydrogen integration.

The content is divided as follows:

1) Analysis of previous deliverables, literature and other projects
2) Identification of most promising markets applications. Four applications have been selected based on work developed in D6.3, D6.4 and on-going D6.8:
    - Electrification in Denmark
    - Gas grid injection in Scotland
    - Mobility in Sweden
    - Industrial in France
3) Identification of main barriers and difficulties for each application
4) Incentives and recommendations for each application

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1. INTRODUCTION

As described in ELY4OFF project Grant Agreement, two deliverables deal with RCS (*Regulations, Codes and Standards)* analysis:

- D6.1 (M15): Guidelines and recommendations to overcome RCS barriers
  - Introduction and definition of the different types of RCS documents;
  - Overview of relevant RCS documents in the hydrogen field;
  - Preliminary list of identified barriers to hydrogen energy applications development and provides some recommendations to overcome them.
- D2.2 (M30): RCS analysis at EU and international level

The objective of this deliverable is to focus on detailing recommendations and incentives for specific off-grid hydrogen applications considered as promising by ELY4OFF partners. For the most promising off-grid hydrogen markets to be identified in WP6, the main objective is to identify the most relevant and efficient incentives and recommendations (at RCS level, economic level and communication level) to foster the deployment of hydrogen technologies.

Deliverable 2.2 is divided in three main parts:

1) Identification of most promising markets applications by analyzing several techno-economic materials, previous deliverables, literature and other projects;
2) Identification of main barriers and difficulties for each application using HyLAW database;
3) Recommendations for each application.

In addition, an analysis of PV deployment trends will help define a size or range of sizes required to address the opportunities. This may in turn feed into the list of design considerations for eventual exploitation. A brief analysis is included in the Annex 2.

2. BUSINESS CASES AND MARKET OPPORTUNITIES

2.1 Analysis of deliverables related to the task

➢ **Analysis of D6.3 First version of new business model for electrolyser in off-grid installations**

This deliverable was submitted in M20 (November 2017). It is a preliminary report asking the questions to find a new business model for off-grid electrolysis. Three main key issues are analysed:

✓ Background on business models: several model types are shown in an off-grid compatibility way.
✓ The main four potential markets are stablished here for first time in the project: industry, mobility, gas grid injection and re-electrification.
✓ Key Stakeholders in new business models: who is who, role of end users, relationship between actors, incentives and benefits, how to commit public authorities.

It can be concluded that a major key economic driver is the use of renewable energy to deliver green power to green gas. The Ely4off project will demonstrate on a small scale that the deployment of large scale off-grid will allow to produce a primary fuel source that can deliver heat, mobility and power

➢ **Analysis of D6.4 Assessment of market potential**

This deliverable was submitted in M25 (April 2018). The main objective of this deliverable is to present different markets and its potential for the implementation of Ely4off. A series of assumptions, indicators and results of economic viability are applied for each market.

The following conclusions are obtained:

- ✓ Energy system for isolated areas: Gensets with batteries are still the most reasonable solution for the specific consumptions assumed in the assessment. Based on mountain huts and their economic assessment, Slovenia would be the best option over France and later over UK.
- ✓ Off-grid HRS to supply FCEVS: with highly intensive energy sources as wind power, the off-grid systems are economically feasible. If not, the electrolyser must be oversized to face the intermittency of the energy source. Based on wind production and its economic assessment, Germany would be the best option over Slovenia and later over France.
- ✓ Weak grids and backup generators: it seems to be competitive and also a good solution in the case of weak grids inside less developed countries, as African ones, providing a service when the scarce electricity grid fails. Based on the economic assessment of weak grids, Benin would be the best option, over Ivory and later over Mali.
- ✓ Green hydrogen for niche industrial applications: the most developed countries are the ones that should start to move towards the hydrogen transition. Based on social indicators, France and Germany would have the highest industry scale over Slovenia. Otherwise, Germany would be the winner in emissions, followed by France and later Slovenia.

➢ Analysis of on-going task 6.8 Business cases analysis

In task 6.8 of ELY4OFF projects, modelling and simulation of specific business cases was carried out to contribute to the techno-economic evaluation of off-grid hydrogen applications.

Business cases presentation, associated hypothesis and results of these simulations will be resented in deliverable D6.8 but mains conclusions are given in this report to contribute to the identification of promising business cases.

Three main applications were:

a) Business case #1: Isolated sites electrification

The evaluation of this first business case using ODYSSEY software showed that off-grid production of hydrogen from PV power may compete with PV-Battery solutions when seasonality is important, PV is limited and electrical load remains high during nights.

However, competing with diesel-based solutions remains difficult even with diesel fuel price as high as 3€/liter.

In situations when PV is abundant and less seasonal (South of Europe) PV-BAT systems seem more economically attractive than hybrid solutions associating batteries and electrolysis larger than 10 kW

b) Business case #2: Hydrogen injection into gas grid

For this second business case, simulations were performed in order to target the main following purposes:

1. Compare different configuration of the system at an economic level, that is to say minimizing well-chosen indicators such as the Levelized Cost of Hydrogen – Grid injection based (LCoH2 expressed in €/kg)
2. Evaluate the sensitivity of the location chosen, the type of RES used, the size of the system and the main hypothesis set on the economic results obtained.

24 different configurations were simulated. These are defined by:

a) The type of RES: solar photovoltaic, onshore wind, offshore wind and hydro energy
b) The location: Northern Europe (Shetland Islands, UK) and Middle-Southern Europe (Occitanie region, France)
c) The size of the ELY4OFF installation: 4 model of electrolyzer with a 56, 200, 500 and 1000 kW maximum stack power

The main lessons that can be learnt are the following:

- ✓ The onshore wind configurations are always the most profitable (LCoH2 reaches 4.45 €/kgH2 in the best case). They may compete with biomethane injection costs (Feed-in-Tariff reaches 5.5 €/kg in some European countries) but not with the natural gas price today (0.91 €/kg in hydrogen equivalent).
- ✓ The most interesting size of the ELY4OFF system would be at least over 200 kW maximum power stack of electrolyzer. The largest scale of electrolyzer (1 MW) gives always the best results.
- ✓ The location and especially the meteorological conditions (insolation, wind) have a significant influence on the LCoH2 (on average a difference of two third for solar and a half for wind between the 2 locations studied).
- ✓ The offshore wind energy generation with floating turbines are not too far from the onshore ones in terms of profitability. This option needs to be studied deeper and could be a good opportunity with the expected significant deployment of wind turbines in the North Sea and the decommissioning of natural gas rigs.
- ✓ Almost all the optimization results in ODYSSEY leads to an oversizing of the RES maximizing the H2 injected into the grid as an economic optimum but it increases the amount of energy unused and does not always match with a realistic situation in terms of technical constraints.
- ✓ As the CAPEX of the RES have a significant share in the total costs of ELY4OFF (between one third and three quarter), these parameters are the most sensitive on the LCoH2 calculation. The LCoH2 could be influenced at a value between 5 and 15% depending on the cost estimation.

c) Business case #3: Hydrogen mobility

In this third business case dedicated to mobility applications in isolated zones, different configurations of the ELY4OFF system were simulated to determine the influence of the following parameters on the economic results:

- The type of renewable energy: solar photovoltaic, onshore wind and hydro energy.
- The location: Northern Europe (Iceland) and Middle Southern Europe (Millau)
- The type of end user's H2 loads: captive fleet of buses or cars with various refueling intensities and frequencies.

After a modeling phase on the ODYSSEY software, the minimization of the Levelized Supply Cost of Hydrogen (LCoH2, [€/kg]) for each configuration studied was the main objective of the simulation task.

The main lessons that can be learnt thanks to this study are the following:

- ✓ The best configurations from an economic point of view are those for buses powered by wind energy (Wind-Mil-Bus5 with a 33.08 €/kgH2 LCoH2, including refueling station). Indeed, larger is the amount of H2 supplied (typically for the configurations bus 5 or bus 6), better is the result. Even for the best configurations envisioned, it remains thus 3 times more expensive than the currently theoretical acceptance price at the H2 pump (around 10 €/kgH2).

- ✓ The wind energy gives better results than the PV in the 2 locations studied. The difference between economic results from wind and solar energy is more significant in Iceland than in the south of France. This was expected considering the difference of the yearly capacity factor of each RES in these 2 countries.
- ✓ Electrical cars with a fuel cell range extender give better results on average than pure H2 vehicles for performing the same delivery service.
- ✓ Simulation shows that there is no significant influence of the refueling schedule on the economic results.
- ✓ The configurations tested and optimized lead us to a sizing in the range [10-400] kW for the electrolyzer stack power ([10-80] kW for car cases and [30-400] kW for the bus cases.
- ✓ The ELY4OFF system's sizing strongly depends on the power generated by the RES, more on irregular meteorological events (e.g. absence of sun during 2 months in Iceland) than on the yearly capacity factor of the RES considered. For example, the size of the H2 reservoir has to be increased (over 100m3) for a seasonal storage at high pressure to counterbalance the low insulation, raising problems about safety or legal acceptancy.
- ✓ All the configurations lead to a high amount of unused primary energy (between 40 and 75%) that could be valorize in other applications. The sale of the electricity in excess contributes to lower the LCoH2 only at values between 5 and 13%.
- ✓ The most sensitive parameters identified on the results obtained are the CAPEX of the equipment: the HRS's CAPEX has a larger influence than those for the RES and the electrolyzer.
- ✓ Hydrogen mobility for the niche application considered gives today economic results quite different from those expected from a classic mobility segment: costs are about 3 times higher for buses shuttle services and 7 times for cars captive fleets comparing with the diesel mobility. However, these 2 applications could be relevant in well-chosen isolated places where the supply costs of fossil fuel or electricity is expensive.

Main conclusions:

Based on the modelling and simulation work carried out in task 6.6, it can be observed that each of the three evaluated applications from a techno-economic point might be interesting under certain conditions.

Off-grid hydrogen may represent benefits compared to competing technologies:

- ✓ For electrification of isolated site with high seasonality of renewable power is observed;
- ✓ For gas grid injection when renewable power factor is high and gas grid constraints are limited;
- ✓ For mobility when renewable power factor is high and low carbon mobility is valued.

2.2 Literature and other projects

Main purpose is to analyse literature and other H2 projects to identify what seems most promising based on studies at European levels.

2.2.1 Public studies of interest

Table 1 identifies main public studies that were consulted to contribute to the identification of most promising business cases for off-grid hydrogen.

Study	Who realizes	Information and comments
SCB Study (2014)	Schlumberger	http://www.4is-cnmi.com/feasability/doc-added-4-2014/SBC-Energy-Institute_Hydrogen-based-energy-conversion_Presentation.pdf

	SBC institute	Main outlook: "the value of energy-based hydrogen solutions lies predominantly in their ability to convert renewable power into green chemical energy carriers" The deployment of hydrogen systems requires cost reduction and public support.
AT Kearney study (2015)	AT Kearney Energy transition institute	http://www.energy-transition-institute.com/Insights/Hydrogen.html *idem SBC study, both studies are probably the same although it is not explicitly mentioned.*
Certifhy study (2015)	Hinicio and partners Funded by FCH-JU	http://www.certifhy.eu/publications-and-deliverables.html Compilation of all the literature and resources that have been reviewed for preparing a market analysis and providing some estimations on the long-term market outlook for green hydrogen. Illustration of how the hydrogen market is segmented today, and which are the main applications and users in the various sectors. Estimation on the potential market for hydrogen and green hydrogen in Europe until 2030. The estimations are based on an analysis of current regulatory frameworks and the suggestions of possible policy-driven scenarios.
IEA technology Roadmap Hydrogen and fuel cell **(2015)**	IEA	KEY POINT: Hydrogen can link different energy sectors and energy T&D networks and thus increase the operational flexibility of future low-carbon energy systems.
NREL 2015 **"Hydrogen Energy Storage: Grid and transportation services"**	NREL	Hydrogen energy storage (HES) systems provide multiple opportunities to increase the resiliency and improve the economics of energy supply systems underlying the electric grid, gas pipeline systems, and transportation fuels. This is especially the case when considering particular social goals and market drivers, such as reducing carbon emissions, increasing reliability of supply, and reducing consumption of conventional petroleum fuels.
ENEA study (2016)	ENEA Consulting	http://www.enea-consulting.com/wp-content/uploads/2016/01/ENEA-Consulting-The-potential-of-power-to-gas.pdf The focus of this study is the assessment of the potential of power-to-gas applications, as well as the potential of other power to-X processes able to seize the opportunity of periods of low-cost electricity
IEA	2017	GLOBAL TRENDS AND OUTLOOK FOR HYDROGEN

		http://ieahydrogen.org/pdfs/Global-Outlook-and-Trends-for-Hydrogen_WEB.aspx
FCH-JU study (2017)	Hinicio Tractebel (ENGIE) Funded by FCH-JU	http://www.fch.europa.eu/sites/default/files/P2H_Full_Study_FCHJU.pdf From executive summary: “The focus of this study is to identify these early business cases and to assess their potential replicability within the EU from now until 2025. An essential part and innovative approach of this study is the detailed analysis of the power sector including its transmission grid constraints. This is of key importance for hydrogen business cases, for at least two reasons. First, because electricity grids represent a potential source of revenues via the provision of balancing services1 given that electrolysers are flexible loads, i.e. can adapt their consumption. Second, because the running costs of hydrogen production are mainly determined by the price of electricity and this price may vary depending on local grid bottlenecks and RES curtailment. Already today, low-cost curtailed renewable electricity is available in various locations across Europe, thus representing an opportunity for electrolyser operators to significantly cut their input costs.”
IRENA study	2018	Hydrogen from renewable Power technology outlook for the energy transition http://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power From highlights: Hydrogen produced from renewable electricity – achieved through an electrolyser – could facilitate the integration of high levels of variable renewable energy (VRE) into the energy system. (…) A policy and regulatory framework to encourage the appropriate private investment is critical.
DECHEMA	2018	http://www.cefic.org/Documents/RESOURCES/Reports-and-Brochure/DECHEMA-Report-Low-carbon-energy-and-feedstock-for-the-chemical-industry.pdf It was concluded in this report that switching industrial processes away from fossil fuel to renewable hydrogen will be relatively expensive:” the production costs for ammonia, methanol, olefins and BTX are currently 2-5 times higher than the fossil alternatives. This is related to high feedstock cost (in the case of biomass) and high cost of electricity (in the case of hydrogen-based processes). For electrolysis-based processes it has to be pointed out, that the economic gap is partly intrinsically, as the generation of chemical building blocks from water and CO2 is obviously more energy, resource and cost-intensive than using existing fossil energy carriers.”

Table 1. Public studies dealing with off-grid hydrogen

2.2.2 Main messages from the analysis of these documents

From the analysis of the previously identified documents, although they are not only dedicated to off-grid hydrogen production, it is possible to identify most promising applications for renewable hydrogen.

Classification of potential applications for hydrogen is similar in each document and can be represented as 5 main markets application:

- Hydrogen for Isolated site electrification
- Hydrogen in Weak grids
- Hydrogen for Gas grid injection
- Hydrogen for Industrial applications
- Hydrogen for Mobility

Table 2 summarizes the strengths and weaknesses of market application as presented in these public reports.

	Strengths	Weaknesses
Isolated site electrification	– Hydrogen provides specific service such as long-term storage – Takes advantage of possible excess production – Zero emissions ➔ World trend tends to decarbonisation	– Strong Competition – Low efficiency (electricity to electricity)
Weak grids	– Versatility of hydrogen – Zero emissions ➔ World trend tends to decarbonisation	– Strong Competition – Low efficiency (electricity to electricity)
Gas grid injection	– Real renewable hydrogen – Renewable power storage – Takes advantage of possible excess production – Independence of foreign gas supply	– Cost compared to natural gas – There are still strong legal barriers for high percentage of injection in EU
Industrial H2	– High value application – Large demand – Existing market for hydrogen – Reduced emissions	– Big industrial site not off-grid and requiring logistics and transportation – Cost of alternative feedstock
Mobility	– High value application – Zero emissions ➔ World trend tends to decarbonisation	– Development uncertainty for hydrogen mobility due to lack of infrastructure. – Off-grid justification

Table 2. Strengths and weaknesses market applications

- **<u>Focus on FCH-JU project Certifhy project</u>**

FCH-JU funded project CERTIFHY contributed to an interesting hydrogen market review and identification of drivers for development of green hydrogen.

Table 3 gives a short overview of the outputs of deliverable D1.3 from CERTIFHY project.

Market	Drivers	2025 estimated demand for green H2	2030 estimated demand for green H2

Refineries	The substitution of conventional hydrogen by renewables-based hydrogen in the refining process in order to achieve the 10% transport target in the RED The substitution of conventional hydrogen by low-carbon hydrogen The substitution of conventional hydrogen by low-carbon hydrogen to profit from the CO2 market (ETS).		25% of all hydrogen use in refineries would come from renewables or low-carbon sources; if not physically, through the purchase of GoOs
Chemical industry	CO2 carbon policy (ETS) more sustainable agribusiness food Corporate Social Responsibility and image	As a simple assumption, we could expect that by 2025, 30% of the hydrogen use in this sector is green hydrogen, increase to 40% beyond 2030	
Other industry	Hydrogen purity Corporate Social Responsibility and image.	As a simple assumption, we could expect that by 2025, 30% of the hydrogen use in this sector is green hydrogen, increase to 40% beyond 2030	
Electrification	a) Long term season storage		
Power to gas	b) Low electricity price c) Public support	80% 0.2 Mt/y	80% 0.3MT/y
Mobility	d) Regulations e) Consumer willingness	50% 0.2 Mt/y	75% 0.75 MT/y
Overall	/		17% of demand

Table 3 - Market drivers and demand from Certifhy project

Figure 1 gives an illustration of green hydrogen demand market shares by 2030. Mains markets appear to be Refineries, H2 mobility and Power to gas and to a lesser extent chemical market.

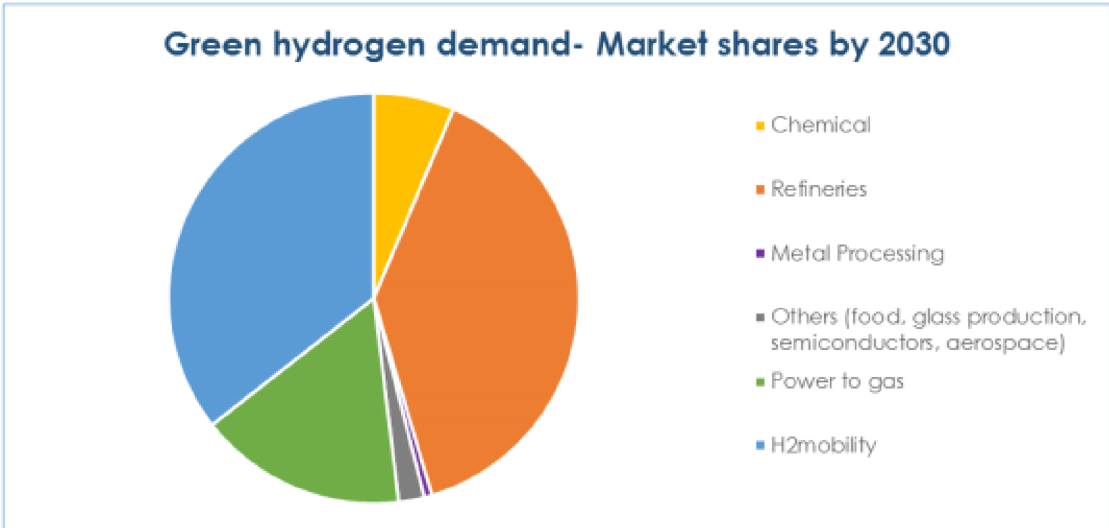

Figure 1. Green hydrogen demand, market shares by 2030 from Certifhy project

Main conclusions

From CERTIFHY project, main markets for green hydrogen are easily identified: refineries, mobility and power to gas. Overall green hydrogen demand in 2030 may represent 17% of all hydrogen demand, i.e. several millions of tons per year.

However, main drivers for development of these markets are different and depend on regulations and public support.

2.2.3 Demo projects on off-grid H2 at European level

An analysis on on-going types of projects aiming at producing hydrogen from renewable sources may help identify interesting business cases.

A discussion between partners allowed for the identification of interesting and representative demo projects in France, UK Spain and other European projects. The list presented Table 4 is not exhaustive but give a good overview of on-going demo projects for off-grid hydrogen.

Project	Country	1st Year of operation	Short Description	Application
MYRTE	FRANCE, Corsica	2012	H2 from PV plant connected	PV storage and Grid service for weak grid
COL du PALET	FRANCE	2017	H2 from PV for isolated mountain hut	Isolated site
Cirque de MAFATE	FRANCE	2017	H2 from PV for isolated village	Isolated village micro grid
GRHYD	FRANCE	2018	H2 from wind energy and grid for mobility and gas grid	Grid injection and mobility
CEOG	FRANCE	2020	Large scale H2 storage and PV plant	PV plant storage and weak grid service

Sustainhuts	Spain	2016	H2 from Hydro power	Isolated site
BIG HIT	UK	2016	Energy from two wind turbines and tidal turbines on the island	Electrification and HRS
GrInHy	Germany	2016	Green Industrial Hydrogen via Reversible High-Temperature Electrolysis	Industrial H2
Demo4Grid	Greece	2017	Demonstration of 4MW Pressurized Alkaline Electrolyser for Grid Balancing Services	Demo4Grid will demonstrate at this demo site with particular needs for hydrogen as a means of harvesting RE production
H2Future	Austria	2017	HYDROGEN MEETING FUTURE NEEDS OF LOW CARBON MANUFACTURING VALUE CHAINS	Grid-balancing services
PECSYS	Germany	2017	Technology demonstration of large-scale photo-electrochemical system for solar hydrogen production	-
BIOROBURplus	Italy	2017	H2 from biogas	-
VITALE	Spain	2018	H2 from different renewable sources	Electrification
KALISAYA	Chile?	2018	H2 from different renewable sources	Electrification
AT SOLAR	Sweden	2018	H2 from 250 kW PV	Mobility

Table 4. Demo projects involving hydrogen from electrolysis

2.2.4 Demo projects analysis

In France, it can be observed that only mountain hut projects can be considered as real off-grid hydrogen projects although some other projects consider that H2 is partly produced from renewable energy. In French overseas territories, especially islands, hydrogen can play a role for massive renewable storage and contribute to grid stabilization.

In Spain, it can be highlighted the project SustainHuts, in which a similar installation to the French project is going to be commissioned in the following months. Real renewable hydrogen produced by hydroelectric source will be used to supply during two months electricity for a mountain hut.

Several other projects aim to developed green hydrogen in Europe as is shown in the previous table, but almost all of them are connected to the grid in order to guarantee maintenance and minimum consumptions required in the equipment’s when there is no renewable energy available. To guarantee this issue is one the most important challenges of the present project ELY4OFF.

Main conclusions

As of today, very few demo projects can be considered real off-grid projects as there have a connection to electric grid. This is because the current status of electrification in off-grid location with hydrogen is facing the challenge of managing the unpredictability and volubility of the renewable sources rather than demonstrating a totally off-grid operation. In other words, it is needed to analyze the electrolyzer behavior and its production ratios whit renewable sources before to be totally isolated.

However, it is expected to create replicability with the few real off-grid projects, pushing demonstration facilities all over EU in order to meet the future standards of decarbonization.

The only real off grid configurations are for electrification of isolated sites or isolated villages.

3. PROMISING OPPORTUNITIES AND BUSINESS CASES IDENTIFICATION

From the previous analysis of (i) ELY4OFF deliverables, (ii) public literature and (iii) on-going hydrogen demonstration projects, opportunities and most promising business cases for off-grid hydrogen may be identified.

The critical elements for opportunities identifications are of different nature:

- Off-grid justification:
    - Real isolated areas → rural areas, mountains in Europe, developing countries
    - Grid not sized to absorb and transport renewable power potential
- High value Hydrogen market
- High value for low carbon content of hydrogen
- Limited or poor competition

Table 5 identifies selected promising business cases associated to the 4 main market applications.

	Application	Localization	Country	Renewable source	Main Driver
1	**Electrification**	Mountain hut in alps	France	Solar	Seasonal storage
		Island	Denmark	Solar	Large storage capacity
2	**Gas grid injection**	Transport network	Scotland	Wind	Renewable storage with limited access to grid
		Distribution network	Italy	PV	Renewable storage with limited access to grid
3	**Mobility**	Green H2 dedicated to mobility	Sweden	PV	Green H2 for mobility / public support

			Spain	PV	Green H2 for mobility / public support
4	**Industrial**	Away from other H2 prod	France	Hydro	Low carbon H2 - regulation
		Isolated area	Greece	PV	No easy access to hydrogen production center

Table 5. Business cases identification

From this table, it was decided between partners to select 4 business cases to be analysed from RCS barriers point of view using HyLAW web database. (https://www.hylaw.eu/database). Countries are selected according to the main criteria of the utility of implementing a certain application, in addition to other considerations. The 4 selected business cases are:

1) Electrification of isolated site in Denmark
2) Gas grid injection in Scotland
3) Mobility application in Sweden
4) Industrial application in France

Each of these business cases are studied in more details in next part.

In addition, for each of the application, countries with no legal and administrative barriers as per HyLAW website classification were identified. It is summarized in Table 6.

	Application	HYLAW topics	HYLAW: no barriers
1	**Electrification**	Stationary FC: Installation requirement	Norway, Sweden, Finland, Germany, Latvia, Denmark, Belgium, Netherlands, France and Spain.
		Stationary storage: land use plan	Norway, Sweden, Belgium, Spain, Denmark, Romania, Bulgaria.
		Stationary storage: permitting requirements	Norway, Sweden, Germany, Denmark.
		Production H2 (localised): simplified process	Sweden, Germany
		Production H2 (localised): land use plan	Norway, Sweden, Latvia, Germany, Netherlands, Belgium.
		Production H2 (localised): permitting process	Norway, Sweden, Latvia, Germany, Denmark.
		Production H2 (localised): permitting requirements	Norway, Sweden, Germany.
2	**Gas grid injection**	Legal framework: permissions and restrictions	None
		Permission to connect/inject	Norway, Germany
		Payment issues	Sweden, Germany
		H2 quality requirements	Sweden, Germany, Denmark, Latvia
		Safety requirements	France, Latvia
		Safety requirements to end-use equipment	Norway, Latvia
		Legal framework: permissions and restrictions	Norway
		Permission to connect/inject	Norway, Germany

		Payment issues	Norway, Sweden, Germany, Denmark, Netherlands, Belgium
		H2 quality requirements	Norway, Sweden, Denmark, Netherlands, Belgium
		Safety requirements	Norway, Denmark
		Safety requirements to end-use equipment	Norway
3	**Mobility**	Stationary storage: land use plan	Norway, Denmark
		Stationary storage: permitting requirements	Denmark, Norway, Germany, Belgium, Netherlands, France, Portugal, Italy, Austria.
		Production H2 (localised): simplified process	Denmark
		Production H2 (localised): land use plan	Norway, Sweden
		Production H2 (localised): permitting process	Norway, Sweden, Austria, Denmark
		Production H2 (localised): permitting requirements	Norway, Sweden, Germany, Netherlands, Spain
4	**Industrial**	Production H2 (centralised): land use plan	Norway, Sweden, Latvia, Germany, Netherlands, Belgium.
		Production H2 (centralised): permitting process	Norway, Sweden, Latvia, Germany, Denmark.
		Production H2 (centralised): permitting requirements	Norway, Sweden, Germany.

Table 6. Countries without barriers according to business cases

From this analysis, it appears that several countries, especially northern Europe countries may be easier targets from a legal and administrative point of view.

4. IDENTIFICACTION OF MAIN BARRIERS FOR EACH APPLICATION OR BUSINESS CASE

The methodology followed for the identification of main barriers in the difference scenarios chosen is as follows:

1) Identify Economic, legal, administrative and societal barriers for each application using FCH JU HyLAW database (https://www.hylaw.eu/database)
2) Identify severity of each barrier using HyLAW database
3) Evaluate the results

It is also worth mentioning that HyLAW project published a document entitled "D4.4 EU regulations and directive which impact the deployment of FCH technologies"

In this report, main regulations and directives classified under different topics are presented and relevant explanations are given.

In the ANNEX 1: HyLAW Database , information on HyLAW database organization is given.

The identification of main barriers is presented below.

4.1 Application 1: electrification

- Market: Electrification of isolated island
- Country: Denmark
- Main driver: Avoid fuel-based electricity production on Denmark island

BARRIER		Severity of the barrier	
Legal and administrative	Stationary FC: Installation requirement	No barrier	green
	Stationary storage: land use plan	No barrier	green
	Stationary storage: permitting requirements	No barrier	green
	Production H2 (localised): simplified process	Data not available	grey
	Production H2 (localised): land use plan	No barrier	green
	Production H2 (localised): permitting process	No barrier	green
	Production H2 (localised): permitting requirements	Data not available	grey
Economic	Cost of hydrogen produced in an off-grid environment	High	red
Societal	Hydrogen acceptation	Low	green

Table 7. Barriers for electrification in Denmark

For this application (electrification in Denmark), there are no main legal and administration barriers identified in HyLAW database.

From economic point of view, the total cost of hydrogen production in an off-grid environment remains the main barrier. This application is part of the main objective of this project, and it requires to be boosted in order to obtain better economic perspective in the future.

From societal point of view, the acceptance of hydrogen as a fuel is not a barrier because Denmark is a good example in the European Union regarding use of hydrogen in several applications.

4.2. Application 2: gas grid injection

- Market: Injection of renewable Hydrogen into natural transport grid
- Country: Scotland
- Main driver: Limited electricity grid transmission capacity and high renewable potential

BARRIER		Severity of the barrier	
Legal Administrative	Production H2 (localised): simplified process	Medium (Operational barriers, Economic barriers)	orange
	Production H2 (localised): land use plan	Low (operation barriers)	yellow
	Production H2 (localised): permitting process	Medium (operation barriers)	orange
	Production H2 (localised): permitting requirements	Medium (Operational barriers, Economic barriers)	orange
	Production H2 (centralised): land use plan	Low (operation barriers)	yellow
	Production H2 (centralised): permitting process	Medium (operation barriers)	orange

	Production H2 (centralised): permitting requirements	Medium (Operational barriers, Economic barriers)	
	Stationary storage: land use plan	Medium (operation barriers)	
	Stationary storage: permitting requirements	Medium (Operational barriers, Economic barriers)	
	Injection of H2 at transmission level: legal framework, permissions and restrictions	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at transmission level: permission to connect/inject	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at transmission level: payment issues	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at transmission level: H2 quality requirements	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at transmission level: safety requirements	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at transmission level: safety requirements related to end users	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at distribution level: legal framework, permissions and restrictions	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at distribution level: permission to connect/inject	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at distribution level: payment issues	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at distribution level: H2 quality requirements	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at distribution level: safety requirements	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
	Injection of H2 at distribution level: safety requirements related to end users	High (Structural barriers, Operational barriers, Economic barriers, Regulatory gap)	
Economic	Cost of H2	High	
	Lack of gas infrastructure	Medium	
	Lack of hydrogen infrastructure	High	
Societal	Promotion and acceptance of general hydrogen use	No barrier	
	Acceptance of Hydrogen into natural gas for domestic application	Low	

Table 8. Barriers for gas grid injection in Sctoland

For this application (gas grid injection in Scotland), there main legal and administration barriers identified in HyLAW database are (i) the permitting and process requirements of producing hydrogen, (ii) the permission to connect to the grid, legal restrictions and requirements, (iii) and the safety issues.

From economic point of view, the total cost of hydrogen remains the main barrier, in addition of a lack of hydrogen infrastructure. On the other hand, there are already transport gas networks and gas platforms dismantled in the North Sea, which is an advantage.

From societal point of view, the acceptance of hydrogen as a fuel can be a barrier but should not be a major issue in Scotland.

4.1 Application 3: mobility

- Market. Mobility
- Country: Sweden
- Main driver: decarbonation of transport applications

BARRIER		Severity of the barrier	
Legal Administrative (from HyLAW database)	Production H2 (localised): simplified process	No barrier	(green)
	Production H2 (localised): land use plan	No barrier	(green)
	Production H2 (localised): permitting process	No barrier	(green)
	Production H2 (localised): permitting requirements	No barrier	(green)
	Production H2 (centralised): land use plan	No barrier	(green)
	Production H2 (centralised): permitting process	No barrier	(green)
	Production H2 (centralised): permitting requirements	No barrier	(green)
	Stationary storage: land use plan	No barrier	(green)
	Stationary storage: permitting requirements	No barrier	(green)
	Road Transport : Road planning	No barrier	(green)
	Road transport : permitting process / requirements	No barrier	(green)
	Road transport : Quantity and pressure limitation	Medium (pressure limited to 250 bars (Structural barrier)	(orange)
	Fuel Origin : legal status and certification of origin	Medium (regulatory gap)	(orange)
	Fuel Quality : quality requirements	Low (economic barrier)	(yellow)
	Fuel Quality : quality measurements requirements	Low (economic barrier, operational barrier)	(yellow)
	HRS : Land use plan	No barrier	(green)
	HRS : permitting requirements	No barrier	(green)
	HRS : Safety requirements	No barrier	(green)
	Cars, buses, trucks : type approval and vehicle registration	Low (economic barrier, operational barrier	(yellow)
	Cars, buses, trucks : restriction and incentives	High (economic barrier, regulatory gap)	(red)
	Cars, buses, trucks : service and maintenance	No barrier	(green)

	Bikes, motorcycles: type approval and vehicle registration	Data not available	
	Bikes, motorcycles: restriction and incentives	Low (Regulatory gap, Economic barrier)	
	Bikes, motorcycles : type approval and vehicle registration	No barrier	
	Boats, ships	No barrier	
Economic	Cost of H2	High	
	Cost of hydrogen fuel cells vehicles	High	
	Competition with electric or hybrid vehicles	Medium	
	Excessive quality	Medium	
	Lack of hydrogen infrastructure	High	
Societal	Public acceptability of H2 for mobility	Low	

Table 9. Barriers for mobility in Sweden

For this application (hydrogen mobility in Sweden), main legal and administration barriers identified in HyLAW database are related to (i) Road Transport pressure limitation, (ii) fuel legal status and quality and (iii) vehicles registration and incentives.

From economic point of view, the total cost of ownership of a hydrogen vehicle remains the main barrier for hydrogen mobility development. The competition with electric or hybrid vehicles is also a barrier to the development of hydrogen mobility. Infrastructure (hydrogen transport and HRS) development cost is also a strong barrier as heavy investment is necessary to develop a sufficient hydrogen network infrastructure.

From societal point of view, the acceptance of hydrogen as a fuel can be a barrier but should not be a major issue in Sweden.

4.1 Application 4: industrial

- Market: Industrial H2
- Country: France
- Main driver: RED II directive implementation

BARRIER		Severity of the barrier	
Legal Administrative (from HyLAW database)	Production H2 (localised): simplified process	Medium (structural barrier)	
	Production H2 (localised): land use plan	Medium (structural barrier)	
	Production H2 (localised): permitting process	Medium (Economic barriers, Operational barrier)	
	Production H2 (localised): permitting requirements (including safety distances)	Medium (operational barrier)	
	Production H2 (centralised): land use plan	Medium (Structural barrier)	
	Production H2 (centralised): permitting process	Medium (Economic barriers, Operational barrier)	
	Production H2 (centralised): permitting requirements	Medium (operational barrier)	
	Stationary storage: land use plan	Low (operational barrier)	
	Stationary storage: permitting requirements	Medium	

	Road Transport : Road planning	No barrier	
	Road transport : permitting process / requirements	No barrier	
	Road transport : Quantity and pressure limitation	Medium (cost)	
	Grid connection : legal status of power to gas plant	High (regulatory gap)	
	Grid connection : Power-to-gas plants and their role in the electricity balancing market	Low (operational barrier)	
Economic	Cost of H2	High	
	Cost of high pressure storage	Medium	
	Lack of infrastructure	low	
Societal	Green H2 for industrial applications	No barrier	

Table 10. Barriers for industrial applications in France

For this application (industrial hydrogen in France), main legal and administration barriers identified in HyLAW database are related to (i) Production and storage permitting process and requirements and (ii) legal status of power to gas plants.

From economic point of view, the cost of renewable hydrogen production compared to hydrogen from Steam Methane Reforming remains the main barrier. The lack of hydrogen infrastructure should not be a problem if hydrogen is produced locally.

From societal point of view, the acceptance of hydrogen as a green chemical should not be an issue.

5. RECOMMENDATIONS TO OVERCOME BARRIERS

Following the identification of main barriers, for each application, more details are given on each barrier (details are taken from HyLAW database) and recommendation is given on how to face this barrier. Proposed recommendation can be for example:

- Legislative action: simplify process or propose legislation to favor green hydrogen application
- Incentive: propose economic incentive to favor green hydrogen application at the customer level
- Public investment: public subsidies to contribute to the development of green hydrogen applications

5.1 Application 1: electrification

BARRIER	Barrier	Analysis and Recommendations	
Economic	Cost of hydrogen produced in an off-grid environment	"Incentives are crucial in the implementation phase of new technologies" ➔ INCENTIVES	
Societal	Hydrogen acceptation	No barrier	

Table 11. Recommendations to overcome barriers for electrification in Denmark

There are no barriers in Denmark for the integration of hydrogen as an energy carrier. The lack of economic incentives can be just improved by means of the national government.

5.2 Application 2: gas grid injection

BARRIER	Barrier	Analysis and Recommendations	
Legal Administrative	Production H2 (localised): simplified process	"In Scotland a PPC application takes several months and cost 35.000€ to 58.000€ with ongoing reporting requirements and cost which impacts small scale projects. It could help to cut the steps by making them to run in parallel, and also to low prices for small scale projects by making prices proportional to the scale." ➔ SIMPLIFY THE PROCESS	
	Production H2 (localised): land use plan	"From a land use perspective, production should be allowed in the same zones as RES generation or Natural gas Production in order to incentivize the use of existing installations as well as the cooperation between RES and hydrogen. " ➔ LEGISLATION	
	Production H2 (localised): permitting process	"The process of developing and publishing permitting guidelines will highlight the need for specific rules. Such rules should aim to streamline the permitting process, provide more clarity and certainty to Ptg operators while ensuring the development of safe and secure infrastructure." ➔ SIMPLIFY THE PROCESS	
	Production H2 (localised): permitting requirements		
	Production H2 (centralised): land use plan	Same as localised level	
	Production H2 (centralised): permitting process	Same as localised level	
	Production H2 (centralised): permitting requirements	Same as localised level	
	Stationary storage: land use plan	Same as localised level	
	Stationary storage: permitting requirements	Same as localised level	
	Injection of H2 at transmission level: legal framework, permissions and restrictions	"From a broad policy perspective to ensure comparable treatment and a 'level playing field across the EU, the framework for permitting PtG plant and grid connection / injection requirements between the Hydrogen supplier and the gas grid operators should be included within relevant EU regulatory frameworks." ➔ LEGISLATION	
	Injection of H2 at transmission level: permission to connect/inject	"A common approach to managing gas safety and compliance requirements for grid connection and operation is essential. A coordinated EU wide review is needed to establish a consistent basis for all relevant hydrogen safety and compliance matters"	

		➔ SIMPLIFY THE PROCESS	
	Injection of H2 at transmission level: payment issues	"It would be needed incentives for renewable hydrogen and offset costs feed in and connection to the gas grid. A Guarantee of Origin framework for the grid operator is critical to provide a business case justification." ➔ INCENTIVES	
	Injection of H2 at transmission level: H2 quality requirements	"Setting an acceptable upper threshold on hydrogen concentrations is needed to allow for network planning as there is no body of evidence to work with." "Gas Appliance Regulation revisions to allow (a transition to) higher hydrogen concentrations may therefore need to be implemented." ➔ LEGISLATION	
	Injection of H2 at transmission level: safety requirements	"Coordination with national initiatives to validate gas grid operation with significantly higher hydrogen thresholds." ➔ LEGISLATION	
	Injection of H2 at transmission level: safety requirements related to end users	"Standards for gas–fired appliances are currently developed by CEN. These are generally produced in support of the Gas Appliances Directive (GAD) 2009/142/EC, soon to be replaced with the Gas Appliance Regulations ((EU) 2016/426) and which the UK has adopted." ➔ LEGISLATION	
	Injection of H2 at distribution level: legal framework, permissions and restrictions	Same as at transmission level	
	Injection of H2 at distribution level: permission to connect/inject	Same as at transmission level	
	Injection of H2 at distribution level: payment issues	Same as at transmission level	
	Injection of H2 at distribution level: H2 quality requirements	Same as at transmission level	
	Injection of H2 at distribution level: safety requirements	Same as at transmission level	
	Injection of H2 at distribution level: safety requirements related to end users	Same as at transmission level	

Economic	Cost of H2	"Incentives are crucial in the implementation phase of renewable sources and hydrogen-based technologies" ➔ INCENTIVES	
	Lack of gas infrastructure	It is crucial to use the old gas infrastructure used in Natural Gas, such as the Scotland-Northern Ireland Pipeline ➔ INCENTIVES	
	Lack of hydrogen infrastructure	"Incentives are crucial in the implementation phase of new technologies" ➔ INCENTIVES	
Societal	Promotion and acceptance of general hydrogen use	No barrier	
	Acceptance of Hydrogen into natural gas for domestic application	General increasement of hydrogen knowledge and a "greener vision" of the gas grid system.	

Table 12. Recommendations to overcome barriers for gas grid injection in Scotland

Main barriers are related to legislation, incentives and simplification of the process, which just can be improved by means of national government.

5.3 Application 3: Mobility

- Market: Mobility
- Country: Sweden
- Main driver: decarbonation of transport application

BARRIER	Barrier	Analysis and Recommendations	
Legal and administrative	Road transport: Quantity and pressure limitation	"Transport safety of high-pressure hydrogen has to be proved. No regulation is stopping so the impact should not be overestimated. Since higher pressure than 250 bar have not been used for transportation of gasses, it needs to be shown that this can be done safely, but no explicit regulation forbids it. The costs for transporting hydrogen in this manner is uncertain so far." ➔ LEGISLATION	
	Fuel Origin : legal status and certification of origin	"The national ambition for reducing GHG–emissions is high, but the lack of a coherent plan for implementing the alternative fuels Directive and the lack of a green hydrogen definition can be a barrier that will slow down the implementation of hydrogen as a zero emission fuel." ➔ LEGISLATION	
	Fuel Quality: quality requirements	"Excessively high purity requirements influence the production cost for hydrogen, which, in turn, influence the total cost of ownership for hydrogen vehicles as well as delay the implementation of hydrogen." ➔ LEGISLATION	
	Fuel Quality: quality measurements requirements	"There are limited possibilities to find actors who can do a complete measurement of hydrogen due to competence and measurement equipment. " ➔ Favour industrial development of H2 actors	

	Cars, buses, trucks: type approval and vehicle registration	"The impact of the LAP is high if the process of getting a type approval is delayed. Delay of the implementation of H2–vehicles." ➔ LEGISLATION	yellow
	Cars, buses, trucks: restriction and incentives	"Incentives are crucial in the implementation phase of new technologies. Incentives reflect the ambition level of the national politicians. Delay of the implementation of hydrogen vehicles." ➔ INCENTIVES	red
	Bikes, motorcycles: restriction and incentives	"Since these types of incentive are not normally used in Sweden it does not constitute a barrier. If there were such incentives it could probably increase sales, at least in the medium term." ➔ INCENTIVES	yellow
Economic	Cost of H2	"Incentives and access to low electricity cost are crucial Alternative fuel directive" ➔ INCENTIVES	red
	Cost of vehicles	"Incentives are crucial in the implementation phase of new technologies" ➔ INCENTIVES	red
	Competition with electric or hybrid vehicles	Medium ➔ Identify most promising mobility markets	orange
	Excessive quality	Excessively high purity requirements influence the production cost for hydrogen, which, in turn, influence the total cost of ownership for hydrogen vehicles as well as delay the implementation of hydrogen. ➔ Work on hydrogen quality standards at European level	orange
	Lack of infrastructure	"Incentives are crucial in the implementation phase of new technologies" ➔ INCENTIVES and Public investment	orange
Societal	Public acceptability of H2 for mobility	Education	yellow

Table 13. Recommendations to overcome barriers for mobility in Sweden

Main barriers seem to be related to (i) total cost of ownership of hydrogen vehicle and (ii) lack of infrastructure. These two barriers need high public investment to favor hydrogen mobility development.

5.4 Application 4: Industrial H2

- Market: Industrial H2
- Country: FRANCE
- Main driver: RED II directive implementation

BARRIER		Analysis and recommendation	
Legal **Administrative** **(from Hylaw database)**	Production H2 (centralised): land use plan	"A hydrogen production unit cannot be installed everywhere; The PLU should be analysed before the planning of the project to choose the appropriate area. This means that the ground parcel on which the H2 production unit will be installed should be eligible for this activity. The process duration to	orange

		change to land use plan is estimated to be the longest from all other countries studied”	
	Production H2 (centralised): permitting process	“The impact is essentially on the project duration. A specific timescale should be planned to delimit the administrative authorization process. The average timescale for this process is between 12 and 18 months” The authorization process for the installation of a hydrogen production unit can take 12(best case) to 18 months (normal case). This time is quite long for units with a small production capacity (ex.: H2 production units for HRS). It is also necessary to have a specific budget for the “risk / damage” study & Environmental Impact study (15 – 20 k€ depending on the project size).” ➔ SIMPLIFY THE PROCESS	
	Production H2 (centralised): permitting requirements	“On safety requirements: Specific H2 detection equipment have to be permanently installed on the production site to monitor the H2 concentration in the atmosphere (if the production is packaged or in–door). The personnel have to be equipped with a mobile H2 detection system for specific maintenance operations, control operations after an accidental shut–down of the unit, restart of the unit etc. The staff needs to be trained on H2 safety & operation On safety distances: Depending on the safety distances which will have been fixed by the safety and risk analysis, following impacts could be listed: the unit could possibly not be installed next to public or private buildings; the safety distances applicable are only known after the risk and safety analysis.”	
	Production H2 (localised): simplified process	“In fact there’s no real simplified authorisation process for decentralised H2 production. The deployment of on–site H2 production for energy application could be lower in France than in other countries. Due to the fact that the legal authorisation process for localised H2 production is the same than for centralised production, this contributes ton long instruction times for projects including on–site H2 production. (mobility, power–to–gas….). The consequence could be that some projects pushed by local or regional collectivises will not be realised due the “regulatory risk” (long time of instruction, uncertain response of the administration, higher costs for the project management…..). It can contribute to lower: – the number of H2 application deployment projects, especially H2 mobility projects; – the “kinetics” of the deployment of H2 as an energy carrier. For industry it can be a market barrier: the deployment of on–site H2 production in France will	

		be lower than in other European countries or even to low for their business development." ➔ SIMPLIFY THE PROCESS	
	Production H2 (localised): land use plan	"A hydrogen production unit cannot be installed everywhere; The Plan Local d'Urbanisme (PLU) should be analysed before the planning of the project to choose the appropriate area to install the station This means that the ground parcel on which the H2 production unit will be installed should be eligible for this activity."	
	Production H2 (localised): permitting process	"The impact is essentially on the project duration. A specific timescale should be planned to delimit the administrative authorization process. The authorization process for the installation of a hydrogen production unit can take 12(best case) to 18 months (normal case). This time is quite long for units with a small production capacity (ex.: H2 production units for HRS). It is also necessary to have a specific budget for the "risk / damage" study & Environmental Impact study (15 – 20 k€ depending on the project size)."	
	Production H2 (localised): permitting requirements (including safety distances)	"On safety requirements: Specific H2 detection equipment have to be permanently installed on the production site to monitor the H2 concentration in the atmosphere (if the production is packaged or in–door). The personnel have to be equipped with a mobile H2 detection system for specific maintenance operations, control operations after an accidental shut–down of the unit, restart of the unit etc. The staff needs to be trained on H2 safety & operation On safety distances: Depending on the safety distances witch will have been fixed by the safety and risk analysis, following impacts could be listed: the unit could possibly not be installed next to public or private buildings; the safety distances applicable are only known after the risk and safety analysis."	
	Stationary storage: land use plan	"hydrogen storage unit cannot be installed everywhere; The PLU should be analysed before the planning of the project to choose the appropriate area. This means that the ground parcel on which the H2 storage unit will be installed should be eligible for this industrial and / or commercial activities."	
	Stationary storage: permitting requirements	"Impact on the ground surface of the storage unit area. If the stored capacity of H2 is over 1 T, the delay for the delivering of an authorisation to operate it could be between 12 and 16 months. Under 1 T of H2 stored, there is no delay to operate when all the formal documents have been submitted"	
	Road transport: Quantity and pressure limitation	"Impact on the investment costs for a new type of transporting vessel for H2. The development of new types of high-pressure vessels for H2 transport,	

		have relatively high costs and long duration, as there is a need to pass a specific type of approval procedure"	
	Grid connection: legal status of power to gas plant	Regulatory gap → Clarify legislation	
	Grid connection: Power-to-gas plants and their role in the electricity balancing market	Operational barrier	
Economic	Cost of H2	→ INCENTIVES → LEGILSTATION (RED II directive application)	
Societal	Green H2 for industrial applications	No barrier	

Table 14. Recommendations to overcome barriers for industrial H2 in France

Some strong barriers remain in France from legislative point of view. It seems necessary to simplify processes and harmonize at European level.

6. CONCLUSION

The results obtained by analysing the four selected business cases will allow to contribute to specific aspects of the design system to ensure compliance with local regulations.

In conclusion, the main recommendations proposed in the deliverable are summarized below:

- Application 1: Electrification (Denmark)

The are no barriers in Denmark for the integration of hydrogen as an energy carrier. The electrification of isolated locations using hydrogen can be a good market niche in this country.

1. Regarding costs, the lack of economic incentives can be just improved by means of the national government.

- Application 2: Gas grid injection (Scotland)

Recommendations: main barriers are related to legislation, incentives and simplification of the process, which just can be improved by means of national government.

1. It could help to cut the steps required for authorization processes in hydrogen production, by making them to run in parallel, and also to lower prices for small scale projects by making prices proportional to the scale.
2. Production of hydrogen should be allowed in the same zones as RES generation or Natural gas Production in order to incentivize the use of existing installations as well as the cooperation between RES and hydrogen
3. Requirements between the hydrogen supplier and the gas grid operators should be included within EU regulatory frameworks.
4. A guarantee of hydrogen origin framework for the grid operator can help to use green hydrogen and to provide a business case justification.
5. Costs: It is crucial to use the old gas infrastructure used in Natural Gas, such as the Scotland-Northern Ireland Pipeline, and promote incentives for the use of new technologies.

- Application 3: Mobility (Sweden)

Recommendations: main barriers seem to be related to (i) total cost of ownership of hydrogen vehicle and (ii) lack of infrastructure. These two barriers need high public investment to favor hydrogen mobility development.

1. Excessively high purity requirements influence the production costs, which influences in the delay of the implementation. Revision of the legislations is required.
2. The lack of a coherent plan for implementing the alternative fuels Directive and the lack of a green hydrogen definition are a barrier that has to be overcome by national legislation review.
3. It is necessary to favour the industrial development of hydrogen actors, to perform measurement in the hydrogen quality requirements.
4. Incentives are crucial in the implementation phase of new technologies.

- Application 4: Industrial H2 (France)

Recommendations: Some strong barriers remain in France from legislative point of view. It seems necessary to simplify processes and harmonize at European level.

2. To reduce the average timescale for administrative authorization process (currently from 12 to 18 months).
3. Ground parcel on which the H2 production unit will be installed should be eligible for this activity.

4. Risk and safety analysis, H2 specific detection equipment and specific control operations are an example of activities which will serve to overcome the process requirements barriers.
5. Promote incentives and legislation (RED II directive application) to reduce costs, both in the hydrogen production and the road transport (quantity and pressure limitation).

ANNEX 1: HyLAW Database organization

1. Production of H2
    a. Centralized electrolysis
        i. Land use
        ii. Permitting process
        iii. Permitting requirements
    b. Localized electrolysis
        i. Simplified process
        ii. Land use
        iii. Permitting process
        iv. Permitting requirements
2. Stationary storage
    a. Land use
    b. Permitting requirements
3. Transport and distribution of H2
    a. Road planning
    b. Permitting process / requirements
    c. Quantity and pressure limitation
4. Hydrogen as a fuel and refueling infrastructure for mobility purposes
    a. Fuel origin
        i. Legal status and certification of origin
    b. Fuel quality
        i. Quality requirements
    c. Fuel measurements
        i. Quality measurements requirements
    d. HRS and H2 delivered to stations
        i. Land use
        ii. Permitting requirements / process
5. Vehicles
    a. Cars/buses / trucks
        i. Type approval
        ii. Restrictions and incentives
        iii. Services and maintenance
    b. Bikes motorcycles
        i. Type approval
        ii. Restrictions and incentives
        iii. Services and maintenance
    c. Boats ships
        i. Design/type approval
        ii. Individual vehicle registration
        iii. Approval for landing
        iv. Operation and maintenance
        v. On board H2 transport
6. Electricity grid issues for electrolysers
    a. Connecting to grid
    b. Legas status of power to gas plants and energy storage
    c. PtG plants and their role in the electricity balancing market
7. Gas grid issues
    a. Injection of H2 at transmission level
    b. Injection of H2 at distribution level
    c. Methanation and injection of methane
8. Stationary power; fuel cells

a. Installation requirements
b. Connection to electricity grid
c. Price of electricity and support mechanisms

ANNEX 2: Photovoltaic deployment trends

Since the main renewable source in the project is photovoltaic generation, the analysis of future business cases and off-grid solutions has to be complemented with information of the photovoltaic future market.

In order to define a size or range of sizes required to address the opportunities, a brief outlook of photovoltaic (PV) deployments trends has been assessed. This information can be used in further considerations for eventual exploitation. The analysis is mainly based in the worldwide implementation of PV, but focused on an off-grid European level.

Different literature is used and reviewed for the analysis of the PV trends, both off-grid and on-grid:

- Off-grid Solar Market Trends from **Lighting Global** (link)
- Global Market Outlook for Solar Power /2018 - 2022 from **SolarPower Europe** (link)
- Trends 2018 in Photovoltaic Applications from **IEA PVPS** (link)
- Data and Statistics from **IRENA** Resource
- Scenarios for the energy sector in Spain 2030-2050 from **Economics for Energy** (link)

Based on the IRENA database, the global investment of solar energy until 2017 at worldwide level is as follows:

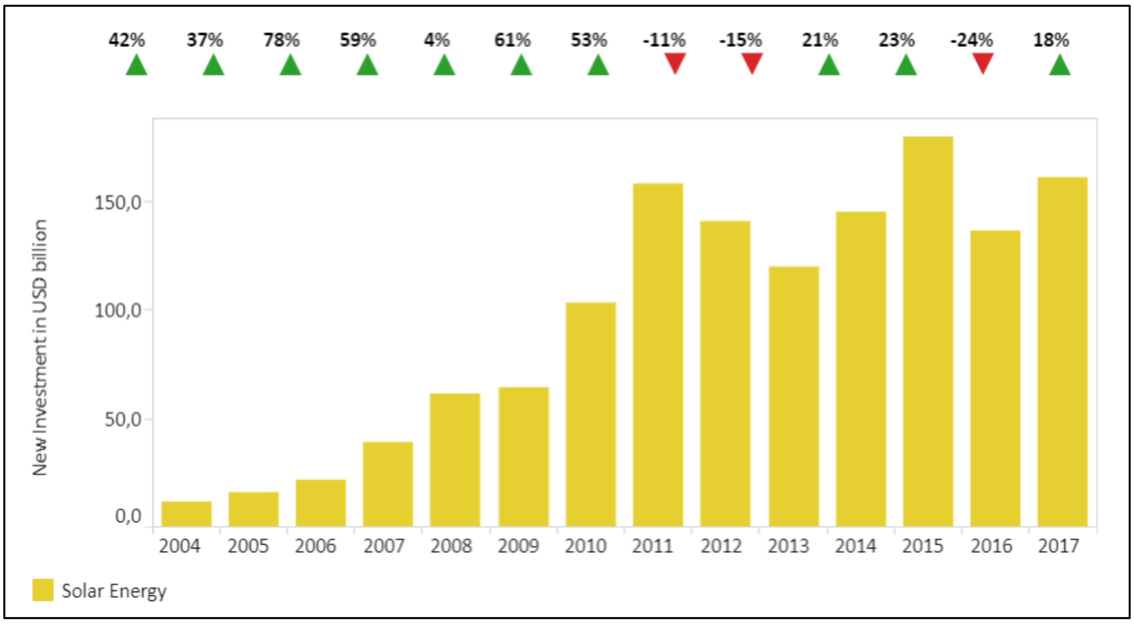

Figure 2. Investment trend in USD billion

This reflects a continuous growth in the solar investment except for a few years. It is required more information to foreseen the future development trends.

By selecting a country within Europe (Spain), an interesting analysis for the future cost of PV technology has been found, in which three main scenarios are assessed (decarbonization: all the efforts are in favour of Paris Agreement; Technological advance: all the efforts are based on the integration of RES; Stagnation: slowdown in economic growth). The following table shows the foreseen investment cost in 2030 and 2050:

Technology	Decarbonization		Technological advance		Stagnation	
Year	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**

PV great scale (€/kW)	800	500	600	350	1000	900
PV small scale (€/kW)	1900	1500	1700	1100	3000	2500

Table 15. Different scenarios for PV future costs.

It can be concluded that the cost reductions from 2030 to 2050 are expected to be between 10 and 40%.

An outlook of the worldwide off-grid PV installed capacity is shown in Figure 3.

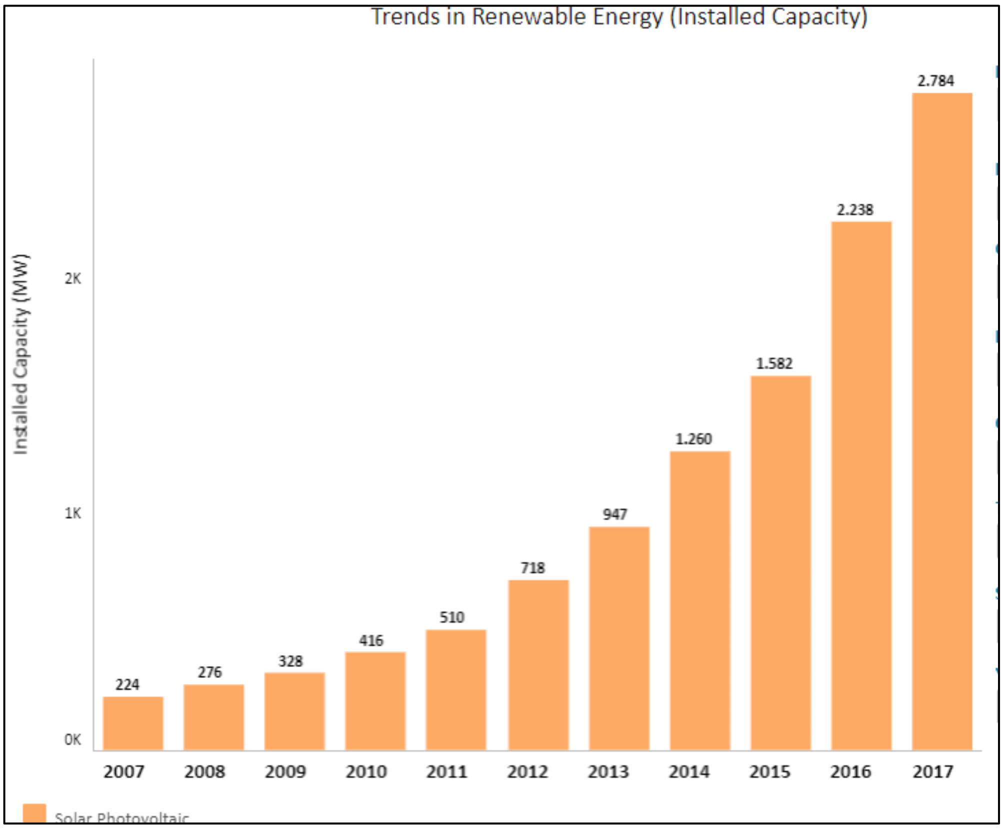

Figure 3. Solar photovoltaic installed Capacity (MW) in off-grid locations

An increasement of more than 1200% compared to the year 2007.

It is also interesting to present the main applications for the PV technology in the European countries during 2017.

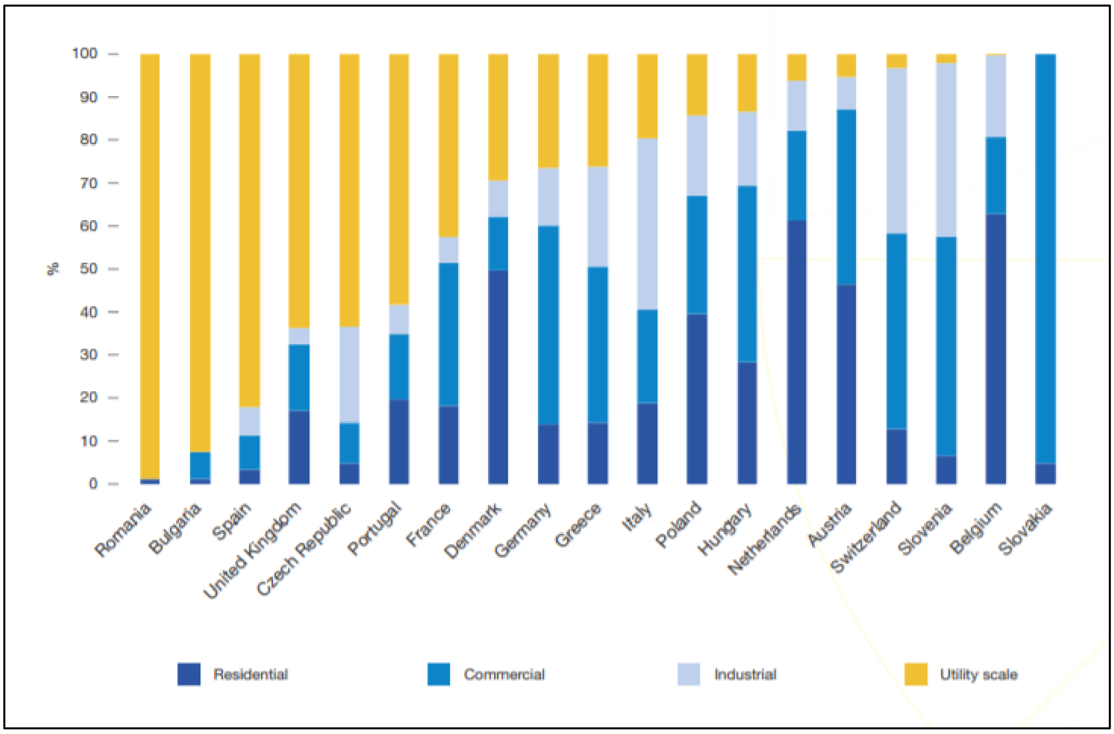

Figure 4. PV total capacity in 2017 for different applications

Small scale PV deployment (residential use) is expected in countries as Spain, in which the legislation has delayed the integration it.

Ely4off can be benefit from the results given in the following figure and in Table 16:

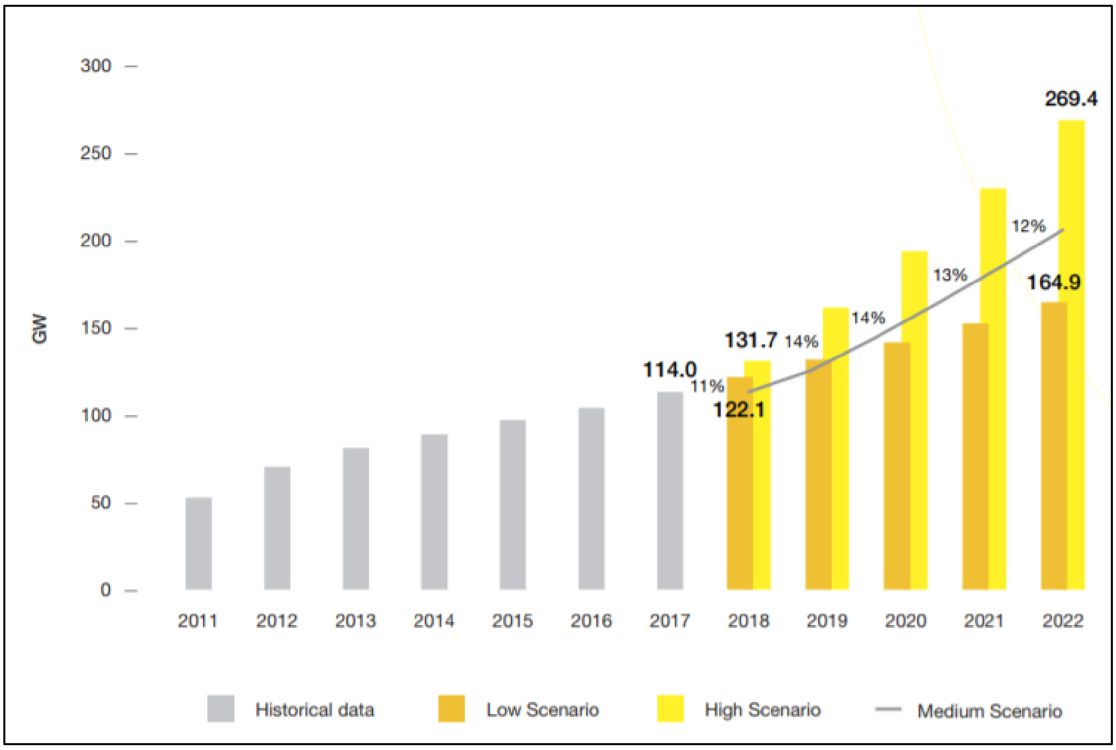

Figure 5. PV trend installation capacity (source: link)

In the highest scenario, it can be expected more than the double of PV installed in Europe. The growth rate expected until 2022 for several countries, is summarized in the following table:

	2017 Total Capacity (MW)	2022 Total Capacity Medium Scenario by 2022 (MW)	2018 - 2022 New Capacity (MW)	2018 - 2022 Compound Annual Growth Rate (%)	Political support prospects
Germany	42,973	63,237	20,264	8%	
France	7,999	19,702	11,703	20%	
Turkey	3,420	14,320	10,900	33%	
Spain	5,627	14,460	8,833	21%	
Netherlands	2,681	11,430	8,750	34%	
Italy	19,392	26,924	7,533	7%	
Ukraine	1,152	4,435	3,283	31%	
Poland	261	2,361	2,099	55%	
United Kingdom	12,676	14,742	2,065	3%	
Switzerland	1,955	3,957	2,003	15%	
Russia	158	1,988	1,830	66%	
Austria	1,263	2,922	1,659	18%	
Belgium	3,708	5,325	1,617	8%	
Greece	2,623	4,210	1,587	10%	
Sweden	317	1,601	1,284	38%	
Rest of Europe	7,651	14,172	6,521	13%	

Table 16. Foreseen new PV capacity installed

Thereby, the prospects until 2022 for the PV are marked by great growth based on the following drivers:

- EU 2020 targets: a number of EU countries have been strengthening their support for solar as the technology is very popular and one of the lowest costs means to increase RES penetration.
- Tenders: solar tender tools have shown to the public the low cost of solar power.
- Self-consumption: solar is cheaper than retail electricity in most European markets and will quickly continua to reduce cost. This is an important trend that will shape the solar power sector in the coming years. Solar is becoming the cheapest source of electricity. But it will only reach its full potential in a real decentralized energy system and recognises the benefits of small scale ➔ Europe is pushing forward small-scale installations that will unlock the economic and social potential of solar technology.
- Emerging & Reawakening Markets: low cost is attracting European countries (new as Belarus or old as Spain).
- Corporate sourcing: it is starting to be seen direct bilateral Power Purchase Agreements with solar increasingly competing with wholesale power market.
- Regulations: new reinforcements to overcome barriers that have inhibited solar's growth possibilities are being implemented.