LUXEMBOURG

Opportunities for **Hydrogen Energy Technologies** Considering the National Energy & Climate Plans

2

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Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU)
Study on Opportunities arising from the inclusion of Hydrogen
Energy Technologies in the National Energy & Climate Plans
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Introduction

The **Fuel Cells and Hydrogen Joint Undertaking** (FCH JU), in close cooperation with the **European Commission - DG Energy**, has commissioned a study on the "Role of Hydrogen in the National Energy and Climate Plans". This study is being conducted by the consultancies **Trinomics and LBST**.

This fiche represents one of the outputs of the study; it comprises two major parts:

- Analysis of **national opportunities for hydrogen deployment**, based on the national hydrogen production and demand potential, the gas infrastructure and the enabling environment. In this context, the role of hydrogen in the current National Energy and Climate Plan is in particular analysed.
- Assessment of **national economic, environmental and technical impacts of hydrogen deployment** under a high and a low scenario.

This information is expected to provide useful information to EU Member States that are considering to include renewable or low-carbon hydrogen deployment in their decarbonisation policies or roadmaps.

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Main results and impacts of hydrogen deployment in Luxembourg by 2030 in the two scenarios modelled in the present study

Electrolysers
70 - 280 MW
96 - 380 GWh_{H2}/a

Solar Photovoltaic
200 - 780 MW
150 - 600 GWh/a

POWER
0.1 - 1 GWh/a

TRANSPORT
90 - 318 GWh/a

BUILDINGS
4- 40 GWh/a

INDUSTRY
2 - 19 GWh/a

10 - 20
Buses

0 - 1
Trains

5 - 11
Refuelling Stations

120 - 230
Trucks

2 800 - 5 600
Cars

0 - 5.6 GWh/a
Electricity Produced

12 - 115 GWh/a
into Synthetic Fuels

190 - 820
Micro-CHP units
in buildings

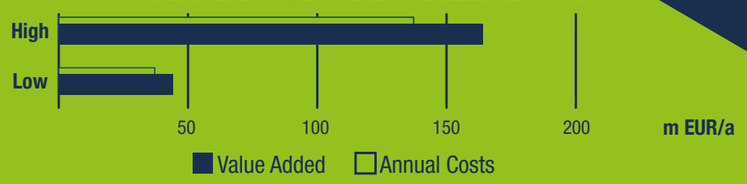
0 - 5
Commercial-scale
CHP installations

Industrial energy demand
2 - 19 GWh/a

44 - 160
m EUR/a

Value Added
in the domestic economy

Value Added as Share of Annual Costs



New Jobs
420 - 1 530

Emissions avoided
47 - 128 kt CO_2/a

EXECUTIVE SUMMARY

Luxembourg's commitment for hydrogen deployment according to its NECP

According to its NECP, Luxembourg wants hydrogen to be part of its energy transition to a low carbon economy, especially in the mobility sector, in the industry and as energy storage vector. Luxembourg also considers hydrogen as an interesting opportunity for its industrial companies and research institutions.[1]

Luxembourg has an enabling environment to address the deployment of renewable hydrogen, as several national organizations and companies are already active in this domain (e.g. List institute, Rotarex Group or the start-up DMA-Tech) and intends to invest in hydrogen infrastructure (e.g. refuelling stations) in order to contribute to the realisation of EU hydrogen corridors that will contribute to decarbonising the transport sector. Luxembourg is currently not involved in IPCEI projects. It was also not involved in the HyLaw[2] project, and could possibly carry out a similar assessment to identify and address its national specific barriers to the deployment of hydrogen.

Luxembourg's NECP does not include specific objectives or targets for the production or use of hydrogen, nor specific measures to promote its deployment.

The scenario assessment shows substantial potential benefits of hydrogen deployment in Luxembourg by 2030

Hydrogen demand

Two (high and low) scenarios of hydrogen demand in 2020-2030 were developed, based on different levels of ambition linked to the national context. The resulting values are summarised in the scheme in the previous page. For Luxembourg, a limited development of hydrogen demand is assumed in the considered scenarios in **transport**, especially for passenger cars, buses and trucks, and to a limited extent in aviation (through hydrogen-based liquid fuels or PtL)[3] and inland navigation. The development of green hydrogen demand in **industry** in the scenarios is assumed only for industrial process heat.

In the **building** sector, hydrogen can replace part of the current use of natural gas and can be distributed via existing gas grids through admixture to natural gas. The building sector is expected to have in the Low scenario a limited demand of hydrogen by 2030 but would have a stronger demand in the High scenario.

The scenarios assume only a marginal share of electricity generation from hydrogen by 2030, coming from combined heat and power installations.

Hydrogen production

To cover the estimated hydrogen demand from new uses and from substitution of fossil-based hydrogen, 0.2 to 0.8 GW of dedicated renewable electricity sources would have to be installed to produce green hydrogen via electrolysis. While "surplus" electricity might be available in times of high renewable electricity production, the main share will have to be covered by dedicated sources.

Estimated socio-economic and environmental impacts

The annual costs to produce green hydrogen (including the cost of dedicated renewable electricity sources), to develop the transport infrastructure (or adapt the existing one) and end-user applications would in the considered scenarios reach respectively 37 and 138 million EUR. These activities will generate value added in the domestic economy, amongst others by creating jobs in manufacturing, construction and operation of hydrogen technologies and will contribute to greenhouse gas emission reductions. This is in particular important in hard-to-decarbonize industries. According to the European EUCO3232.5 scenario[4], the GHG emissions in Luxembourg should be reduced by 1 Mt CO_2 in 2030, compared to 2015. In the scenarios considered, the deployment of hydrogen could contribute 47-128 kt CO_2 to this goal, which is equivalent to 4.7% - 12.8% of the required emission reduction.

[1] *http://www.lessentiel.lu/fr/luxembourg/story/le-luxembourg-jour-la-carte-de-l-hydrogene-17996083*
[2] *https://www.hylaw.eu/*
[3] *Detailed assumptions are available in the methodology annex of the report, that can be consulted via the following link : http://trinomics.eu/project/opportunities-for-hydrogen-in-necps.*
[4] *EC, 2019. Technical Note on Results of the EUCO3232.5 scenario on Member States. Available at https://ec.europa.eu/energy/sites/ener/files/technical_note_on_the_euco3232_final_14062019.pdf*

HYDROGEN IN THE NECP OF LUXEMBOURG

According to its NECP, Luxembourg considers the deployment of hydrogen produced from renewable electricity (mainly photovoltaics and wind power) to contribute to its decarbonization goals. Hydrogen would mainly be used within the industry and transport sectors or as energy storage vector.

According to its NECP, Luxembourg foresees the deployment of hydrogen refuelling stations infrastructure. A certification scheme and standards for "green hydrogen"[5] are essential prerequisites to deploy such delivery infrastructure and allow the injection of renewable hydrogen into the energy system.

Luxembourg intends to cooperate with other European countries on policy instruments and practical measures, including for the development of renewable hydrogen generation and hydrogen refuelling stations along the motorways that are part of EU corridors. In this context, the Pentalateral Energy Forum (PLEF) has organised a workshop to define possible cooperation topics on hydrogen. The five concerned countries will also examine possible common approaches for guarantees of origin, cross-border infrastructure, the respective role of TSOs and DSOs and standards for hydrogen injection. They also intend to exchange information and best practices on support schemes for hydrogen and innovation projects and the future role of hydrogen in general.

The NECP also mentions that, looking ahead to 2030, hydrogen can play an important contribution to security of energy supply and the integration of the electricity, heating, and transport systems.

According to its NECP, Luxembourg expects further cost and technology improvements in hydrogen applications and technologies, in particular in the efficiency of electrolysers and fuel cells. In the field of R&D, Luxembourg intends to cooperate with other EU Member States.

According to Luxembourg's NECP, the major challenge of energy policies is the faster phasing out of fossil fuels than previously planned. For the mobility and transport sector, measures will be taken to reduce the use of cars and trucks. The use of petroleum products for transport is expected to significantly decrease, being mostly replaced by renewable hydrogen and electricity, both for passenger and goods transport. Luxembourg considers stimulating the use of hydrogen for passenger cars, public transport and heavy goods vehicles via its renewable energy target and measures for transport.

According to the NECP, a tax incentive for the purchase of electric vehicles was applied until end of 2018 and has been replaced by direct grants since the beginning of 2019.[6] This programme subsidizes electric vehicles, plug-in hybrid vehicles (≤ 50 g CO_2 / km) and hydrogen fuel cell vehicles.

Further, the military infrastructure on Herrenberg Hill will become self-sufficient in terms of energy. This will include, where possible, conversion of army service vehicles to electricity or hydrogen driven fleets.

[5] Luxembourg considers hydrogen as "green" when produced from renewable electricity

[6] Règlement grand-ducal du 7 mars 2019 portant introduction d'une aide financière pour la promotion des véhicules routiers à zéro ou à faibles émissions de CO_2

OPPORTUNITY ASSESSMENT

Hydrogen production potential & its role in energy system flexibility

The technical potential of variable renewable electricity production in Luxembourg is in EU studies estimated at about 1 TWh annually. This figure is however lower than the volume of variable electricity generation envisaged in the NECP of Luxembourg (1.79 TWh in 2030). As the other renewable energy sources (hydro, biomass) have a limited potential as well, the opportunity to produce in Luxembourg additional renewable electricity for conversion into hydrogen via electrolysis is hence limited.

Similarly, the system flexibility needs are forecasted to remain rather low and would thus, according to the assessment, not create an opportunity for developing power-to-hydrogen conversion as a flexibility provider. The country could however utilize its geographical position next to the large French and German energy markets, to which it is very well interconnected. These markets are expected to have high flexibility needs and also high potential surpluses in variable renewable electricity production, which might create an opportunity for Luxembourg to import renewable electricity for hydrogen production and/or to import hydrogen.

Technical variable renewable electricity potential (TWh/yr)	Technical renewable electricity generation potential compared to forecasted gross electricity consumption in 2030 (NECP)	NECP estimate of variable renewable electricity production in 2030 (TWh/yr)	NECP estimate of variable renewable electricity production in 2030 compared to its technical potential	Ratio between variable power generation capacity in 2030 and average load	Readiness for CO_2 storage
1	16%	1.79	179%	100% (based on EUCO)	Very Low

Luxembourg has limited readiness for producing low-carbon hydrogen through steam methane reforming of fossil fuels using CCS, in particular due to lack of suitable geological CO_2 storage sites.

Energy infrastructure

Luxembourg could assess the feasibility of using its existing methane infrastructure to transport and distribute hydrogen, either by blending it with natural gas or by converting (part of) its network to hydrogen. As there is no publicly available information regarding the share of polyethylene in the distribution network, there is no indication regarding the technical and economic feasibility of such conversion; this aspect should hence be further assessed.

Technical and economic feasibility of converting gas distribution networks to hydrogen (share of polyethylene pipelines in distribution grid)	Natural gas demand in residential and services sectors / length of gas distribution network (GWh/km)	Existing salt cavern natural gas storage sites (TWh)	Suitable geological formations (potential for future hydrogen storage)
N.A	1.4	0	NO
MS range 16%-99%			

There are no salt cavern natural gas storage sites in Luxembourg that could be used for hydrogen, nor underground salt layers that could provide suitable storage opportunities for hydrogen.

Current and potential gas & hydrogen demand

There are significant opportunities for the deployment of hydrogen in Luxembourg, especially in the transport sector and the built environment. In the transport sector, the demand potentials are quite similar to other countries, with the short-term potentials residing primarily in the decarbonisation of road freight and fossil-based rail transport. In the built environment in Luxembourg, natural gas is a dominant fuel in the mix, which could gradually be replaced by renewable or low-carbon hydrogen. On the medium to long term hydrogen could also contribute to the decarbonisation of the part of the heat demand that is currently satisfied with oil-fired boilers. In industry, hydrogen can be deployed to replace existing use of natural gas and for the decarbonisation of supply of high-temperature process heat.

Opportunities for hydrogen demand in industry

In Luxembourg, the contribution of industry to the economy overall is limited, which is also reflected in its share in the overall final energy use, which is only 15%. However, there still seem to be some opportunities for the deployment of hydrogen in Luxembourg's industry. First of all, natural gas accounts for a significant part of the industrial energy mix in Luxembourg, and hydrogen provides an opportunity to decarbonise the gas supply. Furthermore, the industry in Luxembourg stands out in relation to the demand for high-temperature process heat, which represents 60% of the total industrial energy demand. Hydrogen is one of the few low-carbon energy carriers that is well-suited for the generation of high-temperature heat.

Presence of ammonia industry / share of ammonia production capacity in EU28 total	Presence of refineries / Share of Luxembourg's refineries in total captive hydrogen production by refineries in the EU28	Share of Luxembourg in total primary steel production in the EU28	Share of natural gas in industrial energy demand (2017)	Share of high-temperature (>200°C) process heat in industrial energy demand (2015)
0%	0%	0%	43%	60%
MS range 0%-16%	MS range 0%-26%	MS range 0%-30%	Average 32% MS range 0%-43%	Average 38% MS range 9%-60%

Opportunities for hydrogen demand for heating and cooling in the built environment

There is considerable potential for the deployment of hydrogen for the decarbonisation of the built environment in Luxembourg. Natural gas accounts for 36% of the final energy demand in the built environment and half of the demand for heating. Overall, around 80% of the demand for heating is based on fossil fuels. Renewable or low-carbon hydrogen can be used to replace the current use of natural gas in the built environment and on the long term, hydrogen might also be used to replace the oil-fired boilers.

Share of natural gas in the household and service sector energy demand (2017)	Share of heating in the household and service sector energy demand (2015)	Share of cooling in the household and service sector energy demand (2015)
36%	81%	5%
Average: 34% MS range: 0% - 60%	Average: 74% MS range: 41% - 82%	Average: 3% MS range: 0% - 46%

Opportunities for hydrogen demand in transport

Like all EU countries, Luxembourg has a strong opportunity for the use of hydrogen in road transport. This is especially the case for heavy-duty road transport, which accounts for almost half of the energy use in the country's road transport. Additionally, Luxembourg's rail sector is still dependent on fossil fuels for 57% of its energy use. Hydrogen could be one of the solutions to decarbonise this sector, by replacing the existing diesel trains. Next to the road and rail transport sectors, energy use for international aviation is equivalent to 29% of the total domestic energy consumption in the transport sector. Although international aviation is currently not yet covered by European or international climate legislation, EU countries will need to make a collective effort to support the decarbonisation of this sector. Hydrogen and derived fuels are among the few solutions that can be deployed for the decarbonisation of this sector.

Share of heavy transport (trucks, buses & vans) in total energy demand in road transport in 2020	Share of fossil fuels in energy use of rail transport (and absolute consumption) in 2017	Share of inland shipping in overall energy demand for transport in 2017	Energy use by international shipping relative to total (domestic) final energy use in transport in 2017	Share of domestic and international aviation in overall energy demand for transport (incl. energy use int. aviation) in 2017	Share of fossil fuels in energy use of road transport in 2017
47% (12 549 GWh)	57% (176 GWh)	0.0% (0 GWh)	0.0% (0 GWh)	23% (6 678 GWh)	94% (21 259 GWh)
Average 32% MS range 18%-48%	Average 30% MS range 0%-95%	Average 1.5% MS range 0%-9.8%	Average 14% MS range 0%-1011%	Average 14% MS range 1%-25%	Average 95% MS range 79%-100%

Enabling environment: national hydrogen policies and plans, projects and industry

The NECP assessment shows that Luxembourg has not set up a comprehensive framework for the deployment and use of hydrogen yet. It does address hydrogen in its NECP, by referring to its capability to provide flexibility, to convert and store variable electricity, to decarbonize the mobility sector and as an industrial opportunity. It would be relevant for Luxembourg to address the deployment of hydrogen within its broader energy policy to address the decarbonisation challenges across all energy end-use sectors.

Luxembourg is expected to continue its coordination's efforts with the neighbouring countries to properly integrate hydrogen into the electricity and gas systems, and to share experiences and practices with the other Member States (especially the PLEF countries).

In the meantime, it would be appropriate that Luxembourg takes further steps supporting its research centres and industry to carry out hydrogen related research, and to launch where appropriate pilot and demonstration projects, which can contribute to paving the way for the use of renewable or low-carbon hydrogen as a means to achieve deep decarbonisation.

Existence of (or concrete plans for) national hydrogen roadmaps or strategies — Positive environment ✖

An overarching hydrogen roadmap has not yet been developed; such a comprehensive roadmap would support the country in mainstreaming hydrogen within the energy system. The Luxembourg's research organisations and industrial companies active in the field of hydrogen and fuel cell (e.g. in the frame of Lux Innovation[7]) could provide support in structuring such roadmap, in close collaboration with the other PLEF countries.

[7] *https://www.luxinnovation.lu/about-luxinnovation/*

GHG mitigation gap in non-ETS sectors (need for additional GHG reduction measures) — Positive environment

Luxembourg expects to overachieve its non-ETS GHG emission reduction target for 2030. From this perspective, the incentive to implement new measures like those considering the deployment of hydrogen remains limited.

Existence of (active) hydrogen national association — Positive environment ✖

Current and planned hydrogen refuelling infrastructure for the transport sector

Alternative fuels infrastructure directive (2014/94/EU)

In its National Policy Framework (or NPF set in the context of the alternative fuel infrastructure directive (2014/94/EU)), Luxembourg did not include the development of refuelling points for hydrogen accessible to the public. Its commitment to deploy hydrogen refuelling stations has recently been taken and is included within the NECP.

Inclusion of hydrogen in national plans for the deployment of alternative fuels infrastructure (2014/94/EU)	Existence of hydrogen refuelling stations (2019)	which is equivalent to 1 refuelling station per … cars
NO	0	N.A
	Total 156	Average 1 677 543

Existence of (investment on) hydrogen-related projects

There are some companies in Luxembourg that manufacture equipment for the steel industry and that also develop hydrogen-related steel production technologies.[8]

Existing R&D and pilot projects directly related to hydrogen	RD&D annual expenditure on hydrogen & fuel cells (m EUR) (average 2013-2017)	Activities and projects in industry to use hydrogen as feedstock	Number of power-to-gas projects (existing and planned)
NO	0.0	NO	0

[8] *NECP Luxembourg.*

Positive environment

Existence of national tax incentives (CO_2 pricing mechanisms & car taxation)

Luxembourg has set up a CO_2 pricing mechanism in 2014 (the tax is progressively increasing) and has also introduced carbon related taxation for vehicles. Both measures are key to support the progressive shift to low carbon vehicles (including on hydrogen).

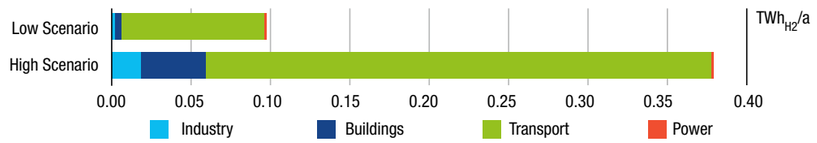
Fossil energy import bill

Like many EU Member States, Luxembourg is strongly dependent on imports for its natural gas as well as its oil consumption. Switching from fossil fuel to nationally produced hydrogen for industrial processes, heating and transport applications will contribute to reducing the import dependence and bill.

	Import bill for natural gas as share of national Gross Value Added	Import bill for all fossil fuels
	N.A	**2.4%**
	Average: **0.6%** MS range: 0% - 1.5%	Average: **2%** MS range: 0% - 7%

SCENARIO ASSESSMENT
Estimated renewable/low carbon hydrogen demand for Luxembourg by 2030

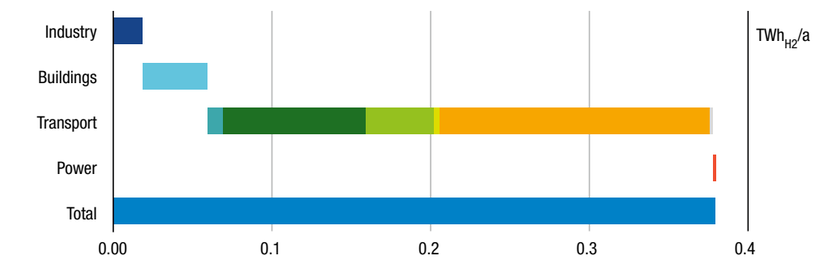
Hydrogen demand in the year 2030 has been estimated in a low and a high scenario covering the range of uncertainty. Today, conventional hydrogen mainly used in industry is produced from fossil fuels (e.g. through steam methane reforming) or is a by-product from other chemical processes. Both scenarios assume that in 2030 renewable hydrogen will be provided to partially substitute current conventional production and to cover additional demand (e.g. from transport sector).



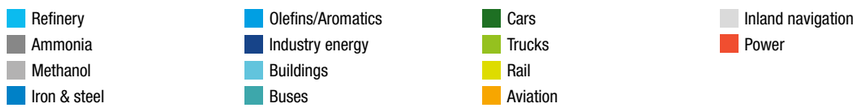
Low scenario

In the low scenario, renewable hydrogen accounts for 0.2% of final total energy demand (i.e. 0.1 out of 51 TWh/a) or 1.5% of final gas demand (6 TWh/a) according to EUCO3232.5.

High scenario



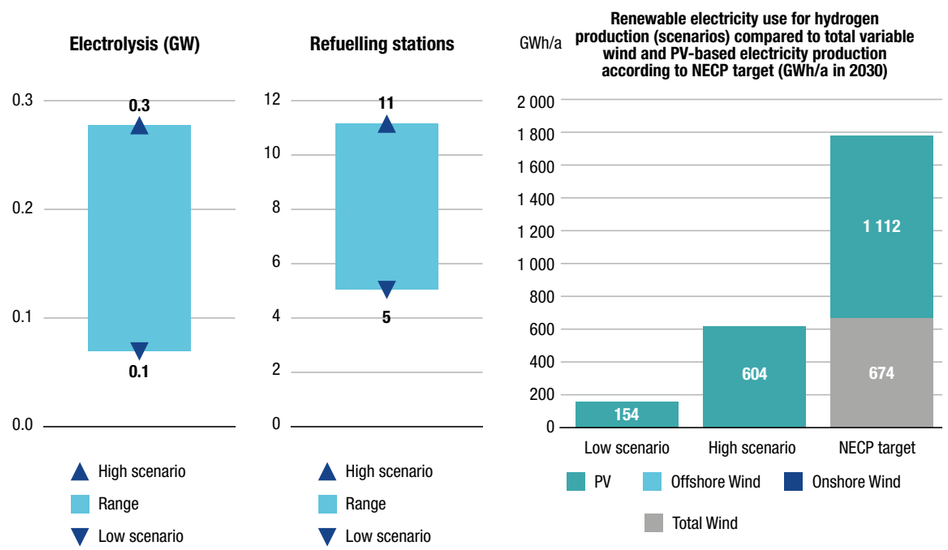
In the high scenario, renewable hydrogen accounts for 0.7% of final total energy demand (i.e. 0.4 out of 51 TWh/a) or 6.1% of final gas demand (6 TWh/a) according to EUCO3232.5.



Hydrogen generation, infrastructure and end users in Luxembourg by 2030

The analysis of renewable hydrogen generation, infrastructure and end use is based on the demand estimates presented above. Renewable hydrogen is generated from variable renewable power using electrolysis. The analysis covers only national hydrogen production to satisfy domestic demand and does not take into account any cross-border trade of hydrogen (i.e. hydrogen imports and exports are not included in this analysis).

Renewable hydrogen generation and infrastructure



The required renewable power production accounts for 11.7% of the overall technical renewable power potential in the low scenario and for 45.9% in the high scenario.

End users

End user	Unit	Low scenario	High scenario
Passenger cars	Nº	2 800	5 600
Buses	Nº	10	20
Lorries	Nº	100	200
Heavy duty vehicles	Nº	20	30
Trains	Nº	0	1
Substituted fuel in aviation	GWh/a	12	115
Substituted fuel in navigation	GWh/a	0.1	0.7
Micro CHP	Nº	190	825
Large CHP	Nº	0	5
Iron&Steel	% of prod.	0%	0%
Methanol	% of prod.	0%	0%
Ammonia	% of prod.	0%	0%

According to the estimations, the hydrogen refuelling station network will by 2030 encompass between 5-10 stations for 3 000-6 000 fuel cell vehicles on the road. [9]

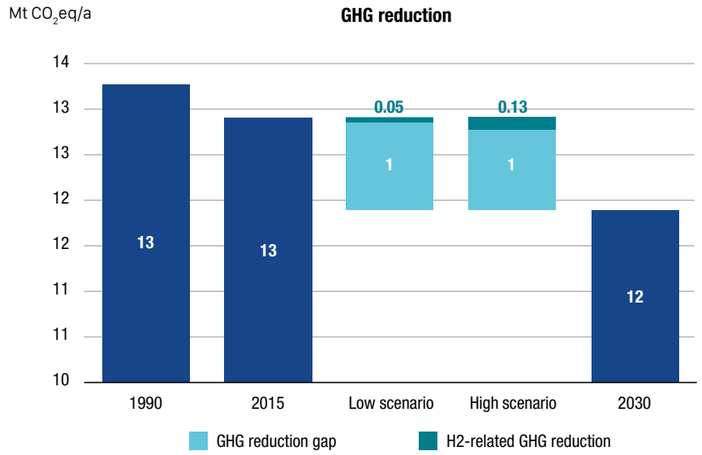
The introduction of 190-825 stationary fuel cells for combined power and heat production is estimated.

[9] *In order to ensure a minimum coverage of the country with hydrogen refuelling stations, more stations may be necessary for supplying hydrogen to the vehicle fleet.*

Environmental and financial impact in Luxembourg by 2030

Greenhouse gas (GHG) emission reductions were calculated by estimating the fuels replaced by hydrogen, and their respective greenhouse gas footprint. Comparing these to the 2030 GHG reduction targets results in the contribution of hydrogen to achieving these targets.

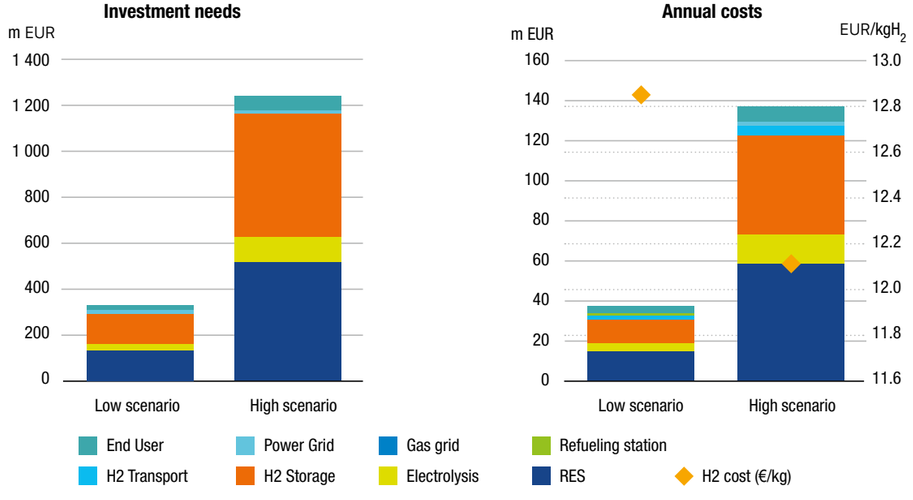
Environmental impact



An additional GHG emission reduction of 0.05-0.1 Mt CO_2 is estimated in 2030 corresponding to 4.7%-12.8% of the overall GHG emission reduction gap towards 2030 target (based on EUCO3232.5).

Financial impact

The financial scenario assessment includes investments (CAPEX) until 2030 and operating expenses (OPEX) per year in 2030. Cumulative investments in hydrogen technologies are estimated at 0.3-1.2 billion EUR until 2030, while annual expenditure would amount to 40-140 million EUR (including end user appliances as well as power and gas grids).

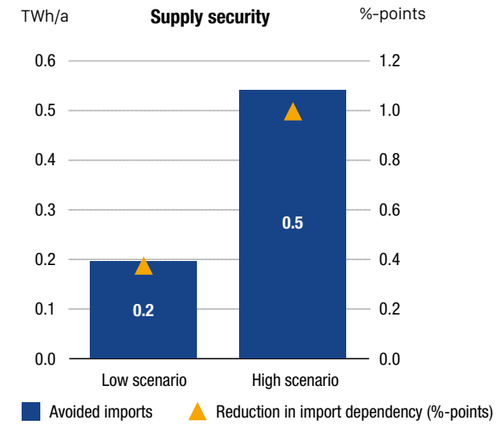


Impact on security of supply, jobs and economy in Luxembourg by 2030

Hydrogen contributes to the energy supply security objective by reducing fossil energy import dependence and enhances energy supply diversification by facilitating deployment of renewable energy sources. This is assessed by estimating imported fossil fuels that will be replaced by hydrogen based on domestic renewable sources.

Security of energy supply

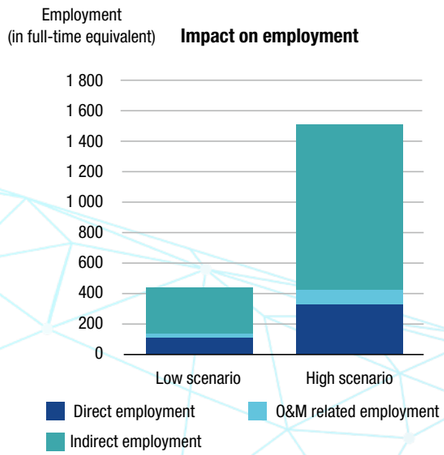
Deployment of renewable hydrogen would lead to 0.2-0.5 TWh/a of avoided imports, and thus reduce import dependency by 0.4-1.0% (in volume terms) in 2030, depending on the scenario.

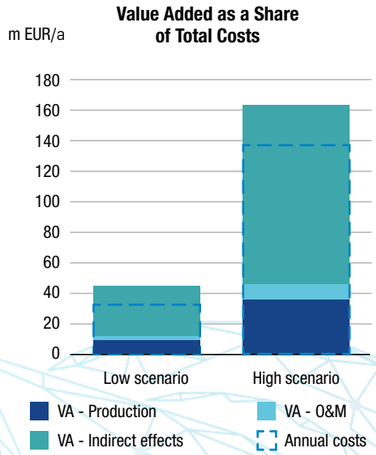


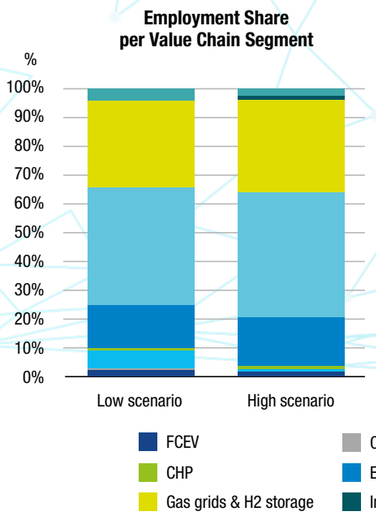
Impact on employment and value added

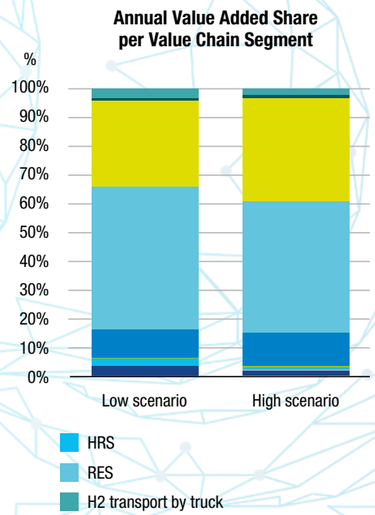
This analysis shows that in the years 2020-2030 around 13 million EUR can be retained annually in the domestic economy as value added in the low scenario, and almost 43 million EUR in the high scenario (value added is defined here as sum of wages for employees, margins for companies and taxes). If the indirect effects induced by the investment in and operation of hydrogen technologies are also taken into account, around 44 million EUR (low scenario) and over 160 million EUR (high scenario) of value added can be created in the Luxembourgish economy annually, which is more than the amount of annual investment needed. Most of this value added is expected to be created by building and operating dedicated renewable electricity sources and electrolysers for hydrogen production, and by developing the necessary hydrogen transport and storage infrastructure.

The hydrogen-related expenditures in 2020-2030 are estimated to generate employment of 110 – 410 direct jobs (in production and operations & maintenance) and contribute to a further 310 – 1 110 indirectly related jobs, depending on the scenario. Most of these jobs are expected to be created by building and operating renewable electricity sources, electrolysers, and hydrogen transport infrastructure.









LUXEMBOURG

Opportunities arising from the inclusion of **Hydrogen Energy Technologies** in the National Energy & Climate Plans

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

2