Sustainable Energy Storage Innovations in Danube Region Countries for the EU-Goals of the Paris Climate Agreement

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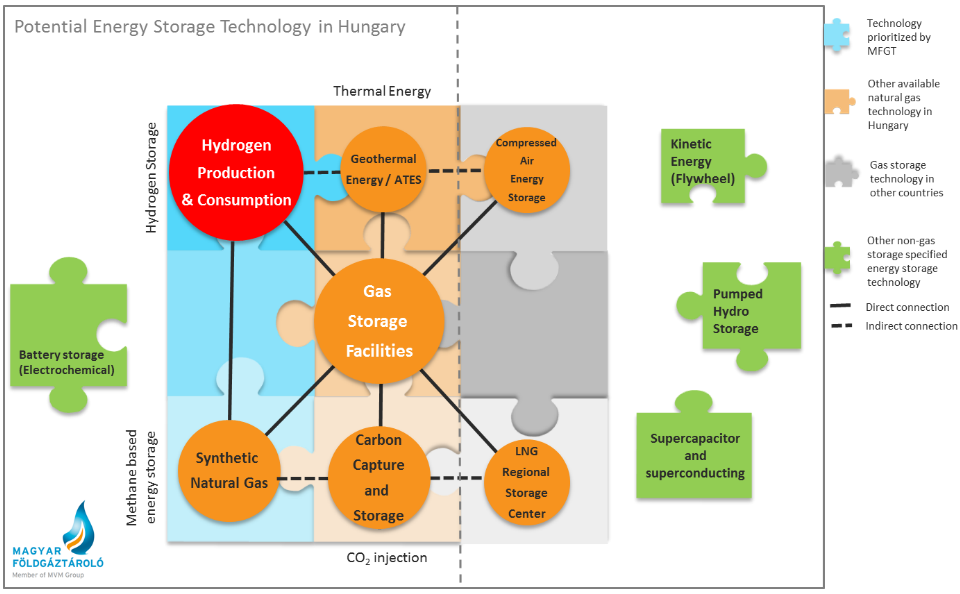
EXECUTIVE SUMMARY

The EU's green strategy particularly promotes the wider spread of renewable energy sources and by this the restructuring of the existing energy system in order to reduce the emission of CO_2 and achieve the emission target set out in the Paris Agreement. **The most critical cornerstone in the spread of renewable energy sources is how to store surplus energy in an efficient way.**

According to the Paris Climate Agreement, EU member countries have a common goal to reduce their carbon-dioxide level by 2030, and Energy Storage technologies offer sustainable, predictable and long-term solutions to achieve this target.

In this study, we focus on the sustainable energy Priority Area (PA2) established in the Danube Region Strategy, more specifically on energy storage. There are two main reasons for this. On the one hand, it helps in achieving the national targets based on the Europe 2030 climate and energy targets, along with the National Energy and Climate Plans. On the other hand, it is a fact that the Danube Region is a bottleneck in the energy sector, which must be solved in order to establish a stable and reliable supply of energy. **Gas storages play significant role in securing the supply in the Danube Region, they provide insurance-, system- and flexibility value in the gas value chain.**

The energy mix of primary energy consumption is expected to be restructured and power consumption will significantly intensify by the end of 2030s. In order to successfully implement sustainable technologies, we have investigated available energy storage methods in general and in natural gas storage circumstances.



In Europe, challenges caused by Carbon Capture and Storage technologies and challenges for the next generation of carbon dioxide-filled underground storages can be tackled.

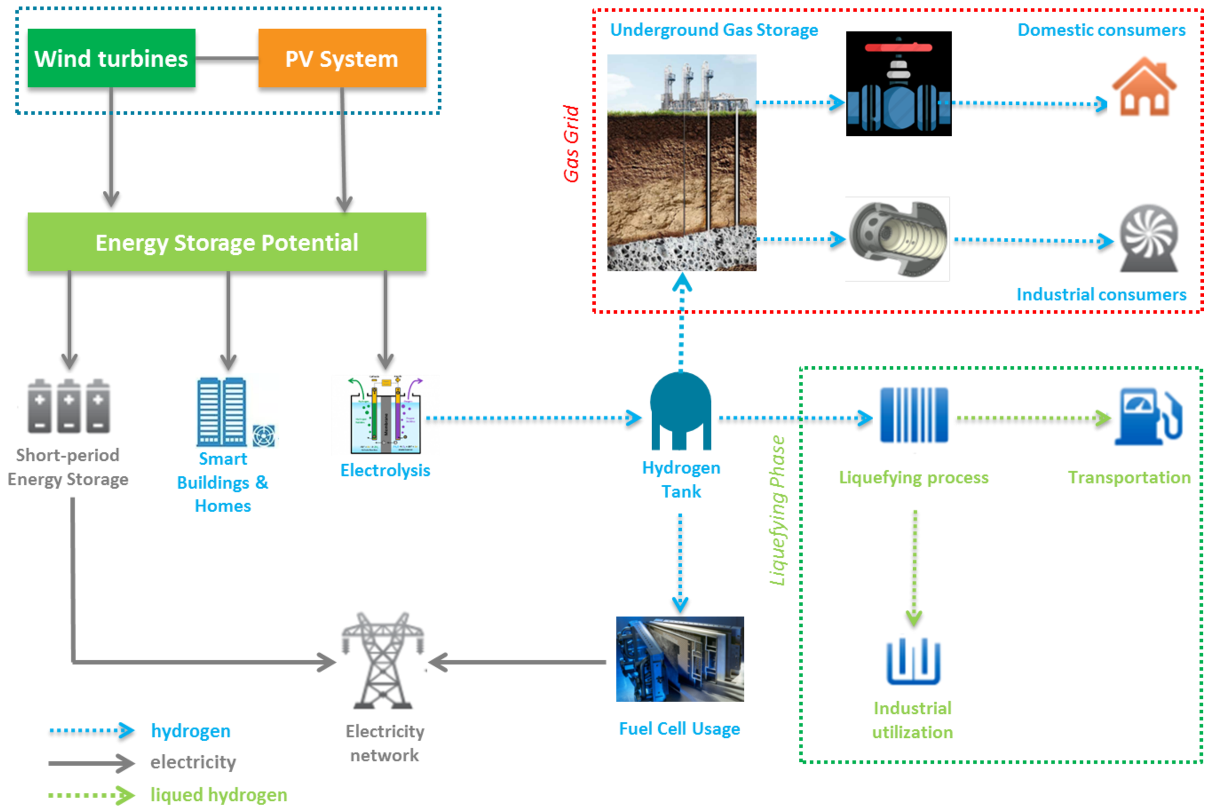
Injecting carbon-dioxide into existing gas storages containing hydrocarbon is not recommended, because it will mix with the gas in place, significantly reducing the energy content. Due to this fact, mainly fully depleted or abandoned gas fields/layers are suitable for CCS-technology.

Where possible, hydrogen is a long-term solution in the energy sector and this versatile energy carrier is the pathfinder for the decarbonisation objective. However, enriching natural gas is a possible way to reduce carbon-dioxide emission **without significantly upgrading the existing infrastructure**. Mature production technologies are the following:

- Electrochemical: by electrolysis process to decompose water into hydrogen and oxygen
- Thermochemical: fossil fuel feedstock. Producing clean hydrogen must be accompanied by CCS process.

In a pragmatic approach, we distinguish between blue hydrogen (depending on the energy mix), green hydrogen (direct connection with renewable sources) and grey hydrogen (mainly produced from fossil fuels). In another classification approach, we also get orange hydrogen (where the main source is biomass via biological or photosynthetic process).

For the natural gas industry, the biggest advantage of hydrogen is that the existing, reliable gas infrastructure which has been in operation for many years now can be modified to be hydrogen-based, thus saving the cost of creating new infrastructure and without having to waste existing infrastructure.



Nowadays, more and more nations are realize the benefits of hydrogen or other low-carbon gases. Most of them are only focusing on research and development, or pilot projects, but there are some that are making significant progress. Depending on the orientation aspects, bottom-up and top-down approaches have strongly connection on the final goals. It is possible that in the near future the use of hydrogen will become increasingly popular since the technology is getting cheaper every day and it is a viable solution in the fight against climate change.

Climate action plans clearly prove that regarding the costs, renewable energy sources and innovations required in order to achieve the goals set out in the Paris Agreement are expensive. This implies that a purely market-based operation of the system is not sufficient. In order to establish sustainable financing for these projects, there are several support schemes around the world, but new, not-yet applied regulations could help establish these new technologies. **It is therefore of utmost importance that we involve regulatory means in the process as well and facilitate the elaboration of a transparent subsidy system.** As countries have different geological and economic characteristics, there is no single silver bullet; tailor-made regulations are required.

At national level, the most common **support schemes are the feed-in tariffs, feed-in premiums, green certificates and investment grants.**

Further important factor is the increasing CO_2 price/ton. At present, it is around €29-€30/ton, and it reflects an upwards trend. According to the European Investment Bank, it could climb to €40-€80 by 2020, reaching €50-€100 in 2030. However, in Germany, there has been a call for a CO_2 taxation system review, which is expected to succeed. Prices will be much higher than in the EU ETS, which then could be easily adopted by the EU, resulting in an overall CO_2 price/ton increase. Considering the fact that we see the ETS as a weapon to combat climate change, the revenues it generates could be channelled into a fund facilitating new and innovative projects in the renewable energy sector. Nevertheless, it requires further and more detailed elaboration.

The decarbonisation process requires a large number of measures. The most vital points are the phase-out of fossil fuels, mainly coal, oil and gas. However, phasing them all out is not possible immediately. According to the merit order of ENTSO's Ten Year Network Development Plan, gas is over coal, since the CO_2 emission of coal burning is circa twofold of that of gas.

In this study, we examine other well written researches. One of them states that while strong electrification can be done, it requires expensive infrastructure investments. As for this investments the majority of this grants would be paid by governments and TSO-s, it's quite possible that these costs would be paid by the price-sensitive residential sector at the end. This means that the already existing gas infrastructure will play a significant role in the decarbonisation process, reducing the costs of the actors with avoiding the necessity of full electrification. Meanwhile other research focuses on two pathways; one is full electrification and the other one is the use of hydrogen as the main energy carrier. First, in the all-electric scenario, there are certain risks. As an example, the all-electric scenario in the transport sector is not possible in the near future due to the characteristics of freight vehicles. The other risk of this scenario is the lack of flexibility since nuclear reactors could not be turned off for days, or turned on occasionally. In the second scenario (where hydrogen is used as the main energy source), the power plants are quite flexible due to the use of hydrogen.

Since hydrogen has zero greenhouse gas emission, it has a clear value to the public, while it can also contribute to fulfilling the commitments that member states assumed to achieve emission targets.

European Union wide 84% people agree with the fact that more public financial support should be given to the transition to clean energies even if that means subsidies to fossil fuels will have to be reduced. Hungary and Slovenia are both first in this in the Danube Region, as 89% of their respondents agree with this. This definitely implies that there is a public support for new clean technologies.

The Frontier Economics published a study with the title of *Value of gas infrastructure in a climate neutral Europe.* It states that the existing gas network is fundamental in decarbonisation and benefits the public acceptance of decarbonisation. They state that gas infrastructure can lessen the pressure on local renewable electricity generation sites. The main reasons are that the gas infrastructure allows us to use:

- Domestic biomethane, as long as it is based on agricultural waste
- Imported green hydrogen or synthetic methane from power-to-gas
- Imported blue hydrogen from natural gas with CSS or CCU technologies

After all, it is evident that utilizing the gas infrastructure with renewable gases, either in storage or energy production is valuable to and supported by the public.

We recommend preparing further feasibility studies for the implementation of hydrogen pathways in each segment in the Danube Region in order to investigate the possibilities of using hydrogen as an alternative energy carrier. It would also be advisable to set up common work groups dealing with the technical and regulatory implementation of the new technology. **As countries have different geological and economic characteristics, there is not a single silver bullet; tailor-made solutions and regulations are required. This study could serve as a blueprint for the development of hydrogen production and utilization in the Danube Region.**

1) ENERGY STORAGE POSSIBILITIES IN GENERAL AND IN UNDERGROUND GAS STORAGE INFRASTRUCTURE

The EU's green strategy particularly promotes the wider spread of renewable energy sources and by this the restructuring of the existing energy system in order to reduce the emission of CO_2 and achieve the emission target set out in the Paris Agreement. The most critical cornerstone in the spread of renewable energy sources is how to store surplus energy. These sources are dominated by solar and wind energy, which are completely exposed to weather conditions and are beyond our control. Using the EU terminology, energy storage in the electricity system would be defined as the act of deferring an amount of the energy that was generated to the moment of use, either as final energy or converted into another energy carrier. Energy storage is recognized and will become a much more important asset in the energy system, since it can support energy security, regulate the internal market, and serve as a core in decarbonizing the European Union. However, electricity storage was not a priority in the past mainly for economic and political reasons, but the introduction and the growing capabilities of renewable energy made its role clear, even if energy storage is rather costly currently. In order to harmonize consumer needs with a renewable-dominated energy supply, we need to store energy.

As shown in *Figure 1*, the energy mix of primary energy consumption is expected to be restructured and power consumption will significantly intensify by the end of 2030s. According to the BP Energy Outlook 2019, if the transition continuously tends towards a lower-carbon energy system, renewables and natural gas will play major roles in the decarbonisation process. These two energy sources will account for almost 85 % of the total growth by 2040. Furthermore, renewable energy is the fastest-growing source: its share in primary energy consumption will increase from 4 % today to around 15 % by 2040. Natural gas consumption rises massively due to increasing availability and widespread use. Another reason that drives the growth is the expansion of LNG supply, which will overtake inter-regional pipeline shipments in the late 2020s. There is a noticeable contrast if we examine coal consumption in the global market. While OECD countries switch coal or lignite to cleaner, lower-carbon (or almost carbon-neutral) fuels, the overall figure stagnates, because it is offset by the increasing consumption demand of Asian countries, especially India. Despite the expansion of natural gas and renewable sources, the share of oil consumption continues to dominate (especially in the transportation sector), plateauing in primary energy consumption after 2030. [[1]]

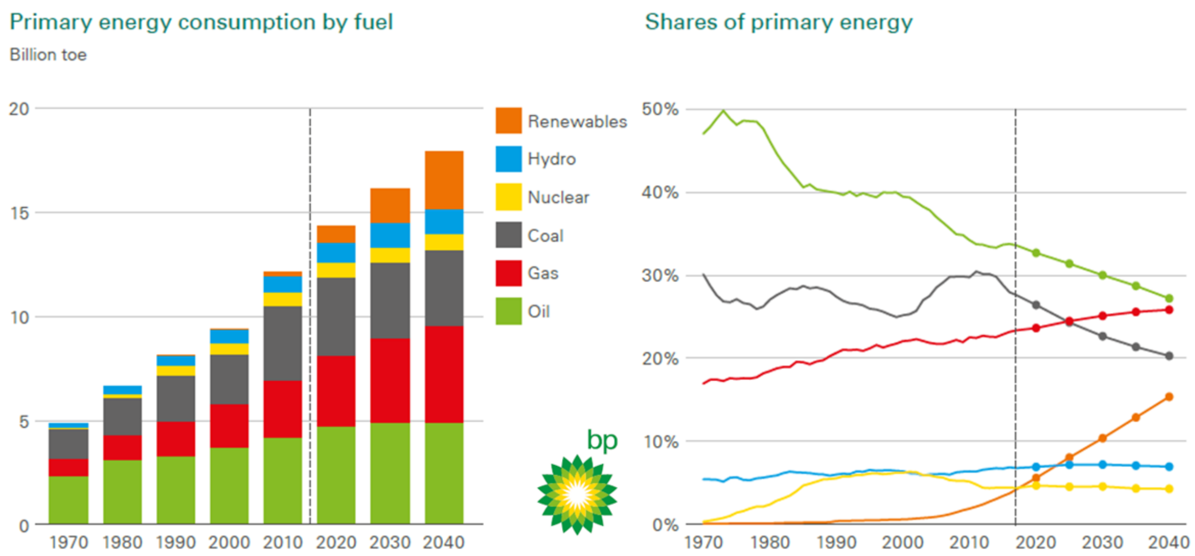


Figure 1: *Primary energy consumption by fuel and shares of primary energy* [1]

In order to successfully implement suitable technologies, we must consider available energy storage methods for the following main traditional reasons:

- Continuous and flexible energy supply needs (cheap but fluctuating power sources)
- Geographical distance between production and consumer (decentralization)
- Significant demand for renewable energy sources (weather dependency)
- Smart grid requires optimized, intelligent energy production and consumption
- Network bottlenecks

According to the Paris Climate Agreement (as outlined in Chapter 3), EU member countries have a common goal to reduce their carbon-dioxide level by 2030, and Energy Storage technologies offer sustainable, predictable and long-term solutions to achieve this target. This interest goes hand in hand with the ambition to balance the strong demand for renewables and flexible grid capacity.

[1] BP Energy Outlook 2019, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf accessed 15.10.2019

Discharge times (Y-axis) vs storage capacities (X-axis) are depicted below for these methods (*Figure 2*):

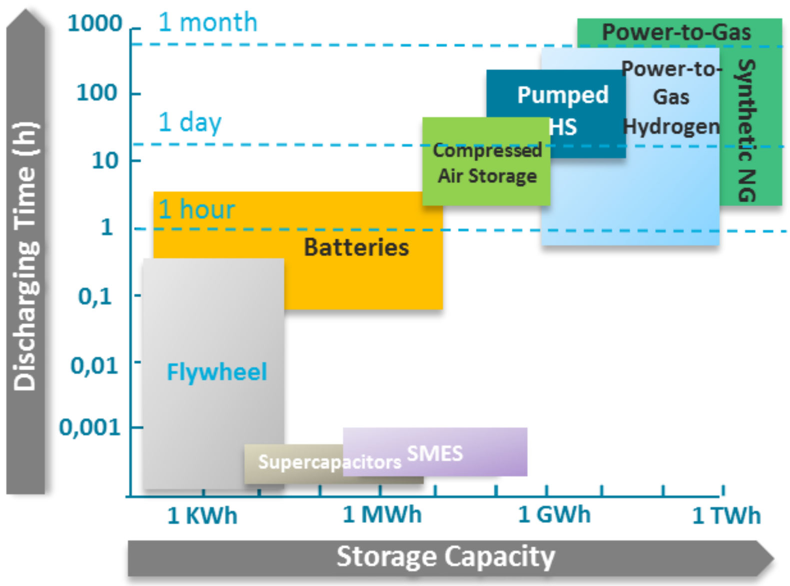


Figure 2: *Discharge times vs. storage capacities of various storage technologies*

Five main available groups of Energy Storage technologies can be distinguished [2] [3]

1. **Mechanical**
   a. Kinetic energy (Flywheel): short-term solution to store electricity with kinetic mass (Low storage capacity and short discharging time)
   b. Potential energy (Pumped Hydroelectric Storage - PHS) : using the potential energy of water to store electricity where geographical requirements are given. Capacity is between 1-10 GWh per cycle and is a massive storage method in both the short and medium term.
   c. Compressed Air Energy Storage – CAES: air compressors are driven by excess electricity (see next section)

2. **Electrochemical** (also known as Battery-storage technologies) It requires a heavy supply of lithium, the mining process of which has a high environmental impact. Although batteries are

[2] European Association for Storage of Energy – Energy Storage Technologies http://ease-storage.eu/wp-content/uploads/2016/07/EASE_TDs.pdf accessed 25.09.2019

[3] ESTMAP – D3.05: Country Energy Storage Evaluation, Prepared by: Serge van Gessel, Vit Hladik, Vladimir Kolejka, Anne Gaelle Bader, Eline Begeman, version: 19.01.2017

still not very efficient as to their price/capacity ratio, and they also raise environmental degradation concerns, they are viable enough to be used on a large scale. Its advantages include flexibility and efficiency; while its disadvantages are limited stored energy and metal feedstock. There are 3 main groups of them:

a. Sodium-sulphur batteries
b. Lithium-ion batteries
c. Flow batteries

3. **Electrical storage**
   a. Supercapacitor
   b. Superconducting Magnetic Energy Storage (SMES)

4. **Chemical storage:** this well-established technology uses renewable electricity to create chemical materials, mostly gases. Although technically it can be easily implemented in the current energy system, it is expensive, as this is a new technology. Its advantages are: massive storage capacity from short to long term, and it establishes an opportunity for sector-coupling (a bridge technology between electricity and natural gas market). Our main aim with this project is to demonstrate the feasibility synergies and the early adaptive potentials of the Hungarian market concerning:
   a. Power-to-Gas Hydrogen: It is produced by electrolysis with excess electricity in flexible part load operations. For further details, see Chapter 3.
   b. Synthetic Natural Gas (SNG): using hydrogen with carbon dioxide to create methane
   c. Methanol, ammonia: industrial solutions using nitrogen and carbon dioxide

5. **Thermal storage**
   a. Molten salt: Salt is solid under ambient conditions. It can change phase from solid to liquid when heated with excess electricity

Another type of approach regarding energy storage is based on the ESTMAP study (Energy Storage Mapping and Planning)[[3]]. This study is a collection, a statistical analysis of surface and subsurface storage potentials of European countries considering the following possibilities:

- Underground Natural Gas Storage (UGS) as chemical storage
- Hydrogen Energy Storage (HES) as chemical storage
- Compressed Air Energy Storage (CAES) as mechanical storage
- Underground Pumped Hydro Storage (UPHS) as mechanical storage
- Underground Thermal Energy Storage (UTES) as thermal storage (molten salt or crushed rock or Aquifer Thermal ES)
- Pumped Hydroelectric Storage (PHS) as mechanical storage

Pumped Hydroelectric Storage (PHS) uses the potential energy of water. Water is pumped from a low level reservoir via turbines to an uphill reservoir with the help of surplus electricity during off-peak periods. When power consumption increases, water flow direction is reversed, and in turn, the uphill reservoir water drives the turbines to regain electricity. The estimated efficiency ranges from 70 % to 85 %. Nowadays, this technology is the most widely used energy storage method with a high level of maturity.
The most common energy storage reservoirs are above-ground lakes with PHS technology, and in Europe, the following countries have the highest potential in this technology: UK, France, Italy, Norway, Germany, Austria, Czech Republic, Sweden and Bulgaria. [[4]]

Depleted gas reservoirs or **reservoirs in aquifer** are widely used energy storage facilities with site-specific characteristics. The most common existing storage infrastructure is Underground Natural Gas Storage (UGS) storing natural gas as a chemical energy source. Hydrogen Energy Storage (HES) in reservoirs or in aquifers requires significant additional research to reach the tipping point for this technology as an industrial alternative.

Another potential utilization of underground storage facilities is CO_2 storage (CCS, Carbon Capture and Sequestration), although this is not a true energy storage solution. For further information see Chapter 3.

Storing energy in **hydrocarbon reservoirs** is a widely used mature technology for natural gas storage (UGS), which has been implemented in many locations in Europe. The main characteristics of this storage type are as follows:

- since HC reservoirs are depleted gas or oil fields, surface and subsurface technologies are well developed, proven, tested and available for storage (e.g. natural gas preparation technology, wells, etc.)
- easy integration into the national gas transmission (and distribution) grid
- technically and economically viable according to feasibility studies
- huge amount of potential working gas capacity suitable for seasonal storage and network balancing with high demand periods of several weeks or even months
- During the withdrawal period (mostly in autumn and winter), natural gas is produced from the reservoir through gas wells to the surface equipment. The gas withdrawn through the wells is usually accompanied with water and liquid hydrocarbons from the reservoir, which is also brought to the surface. The removal of these liquid components is essential to fulfil standards and regulations, so the gas must first be separated to liquid and gaseous phases in separators. Following this, the gas flows through a dehydration equipment, where with the

[4] Bjarne Steffen – Prospects for Pumped-hydro storage in Germany, EWL Working Paper No. 07/2011, December 2011

help of a special treatment, the rest of the water content is absorbed and separated from the gas. In some cases, the gas also contains liquid hydrocarbons, which must be removed as well: either by cooling via expansion or refrigeration. From this point on, the gas becomes ready to be directly fed into the high-pressure transmission pipelines

- During the injection period, natural gas is transported from the transmission system to the UGS site, where it is measured and compressed. Since pressure increase also raises the temperature of the gas, it must be cooled down. Following this, it travels through the flowline manifold and the field lines and then the gas enters through wellheads and wells into the porous storage formation. In Hungary, sandstone and limestone reservoirs are used.

Figure 3 below demonstrates a typical withdrawal and injection period:

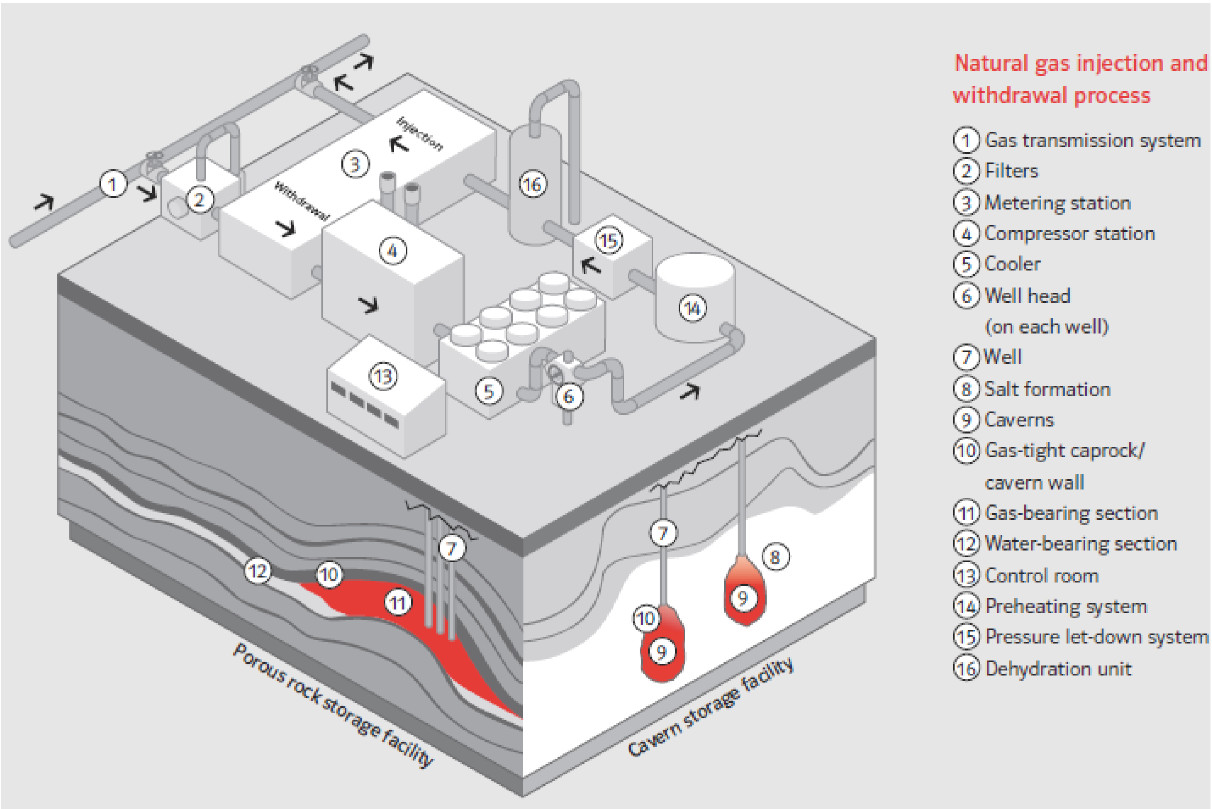


Figure 3: *Typical withdrawal and injection cycle in the Hungarian Gas Storage (Source: own elaboration)*

NB: Pls. note that units 8-10 in the above figure are salt cavern storages, which do not exist in Hungary. For salt caverns, please see below.

Hydrogen Energy Storage in Hydrocarbon reservoirs has the great potential of combining it efficiently with renewable energy sources, e.g. via power-to-gas technology, and integrating it into the energy system. Hydrogen has a small molecular size, thus it can diffuse easily, which is a challenge. As

outlined in the section on aquifer storage, further research is required to prove the sealing capacity of underground storage sites. More details will be provided in Chapter 3.
The most commonly used subsurface hydrocarbon reservoirs are in Germany, Austria, Hungary, Ukraine and Serbia.

Salt caverns and formations are geological formations, which have been formed by the evaporation of saline waters. This process usually contained gypsum and carbonate deposits between rock beds. The cap-rock above these deposits usually has low permeability and can be considered impermeable. This impermeable layer prevents the flow of fluids and gases to the layers above.

When natural gas consumption is low, usually during the summer, gas is injected into the storage site from the transmission pipelines. The entering volume is metered and compressed (if necessary). After this process, natural gas flows through a gas manifold and is distributed into buried pipelines that feed it into wells. These wells lead into artificial caverns leached out by injecting fresh water into a totally impermeable salt layer to form cylindrical shaped cavern (100-300 meters in height and several tens of meters in diameter). The high-pressure gas is channelled through wells into the caverns. When natural gas consumption is increasing, gas flow direction is reversed and natural gas flows back into the well and passes through the buried pipes to the manifold. The produced natural gas is then dehydrated to have water and fluids removed. If the pressure is too low or insufficient to power the transmission, it is compressed. Natural gas is usually odorized for safety reasons before it enters the transmission pipeline. Cavern storage has high flexibility to inject/withdraw into/from the high-pressure gas grid.

Techno-economic feasibility study shows that salt caverns are currently suitable for natural gas storage based on decades of operational experience and there is a proven technology for this geological formation, yet they are rarely used for Hydrogen Energy Storage. Some pilot projects have already been launched in Germany to test the suitability of materials against hydrogen resistance and durability. Microbiological activity, characterization of life-forms, laboratory and experimental assessment and in-situ tests are required to understand the long-term interaction between salt and hydrogen. For storage safety and integrity, degradation and corrosion of materials must be checked, along with the thermodynamic criteria, etc. [5]

Salt formations have a great feasibility potential for CAES because of the high purity of the reservoir (when caverns are created, fresh water is injected through the wellbore and contamination cannot enter the reservoir)
Salt caverns are widely used as Energy Storage reservoirs (generally for natural gas storage and less for hydrogen storage) in Germany. There are some salt formations in Slovakia and in Romania,

[5] http://www.hypos-eastgermany.de/fileadmin/content/downloads/pdf/hypos-whitepaper_zur_strategiefortfuehrung_2017_0.pdf accessed: 21.10.2019

however these geological structures are not typical formations for storage in the countries of the Danube Region (except Germany).

Abandoned mines or mined rock caverns have slight impact on the energy storage methods due to their capacity limitations (according to the ESTMAP, this technology is available only in the Czech Republic in the Danube Region). This formation has tight caverns and should be designed to ensure that they are free of fractures and permeable sections so as to minimize leakage. The subsurface rock must be strong enough and uniform to use it as a storage method. Shale and siltstone are the most preferred rock types. Abandoned mines are considered a main target for UTES as an energy storage possibility (thermal).

Storages	Natural Gas	Hydrogen	Thermal	CAES	UPHS	PHS	CO_2
Aquifer	+++	?	++	?			+
Depleted gas fields	+++	+		?			++
Depleted oil fields	++			?			++
Salt Caverns	+++	++		+			?
Rock formation	+	?	+	?	?		?
Abandoned mines	?		+		?		?
Lakes						+++	

+++ mature technology, ++ proven, + prospective, ? pilots and design

Figure 4: *Feasibility of energy storage methods in various reservoir types* [6]

As *Figure 4* shows, storing natural gas is a widely used and commonly implemented energy storage method in several types of reservoir, with various geological and geophysical attributes (e.g. rock type, cementation, working gas capacity and flexibility). Hydrogen Energy Storage has a potential and a feasible technology in salt caverns and depleted gas fields with adequate sealing rock capacity.

[6] ESTMAP – Energy Storage Data Collection Report, Prepared by: Serge van Gessel, TNO, Anne-Gaelle Bader, BRGM, Anne Bialkowski, BRGM, Laurent Beccaletto, BRGM, Eline Begemann, Ecofys, Page 21, version: 14.12.2016

Future investigations are required to prove the viable feasibility of their utilization as energy storage reservoirs (e.g. corrosion of materials, thermodynamic process and degradation of mines). Thermal energy storage is possible in aquifers, rock formations and abandoned mines due to the unused capacity.

For further specific information about countries see Appendix A (according to the former project of ESTMAP)

2) THE ROLE OF NATURAL GAS STORAGE IN THE DANUBE REGION TODAY

2.1. The EU Strategy for the Danube Region

The Danube Region stretches from the Black Forest in Germany to the Black Sea at the coasts of Romania, Ukraine and Moldova, and covers a population of nearly 115 million people. The importance of this region could not be unrecognized. This led to the establishment of an EU macro-regional strategy that seeks to exploit this region's capabilities to the fullest possible. For this purpose, 4 pillars are required to achieve all the needs regarding the characteristics of economy, transport and socio-economy in this region. The strategy was adopted by the European Commission in December 2010, and endorsed by the European Council in 2011.

Figure 5: *EU Strategy for the Danube Region*[7]

[7] https://danube-region.eu/about/ accessed: 22.10.2019

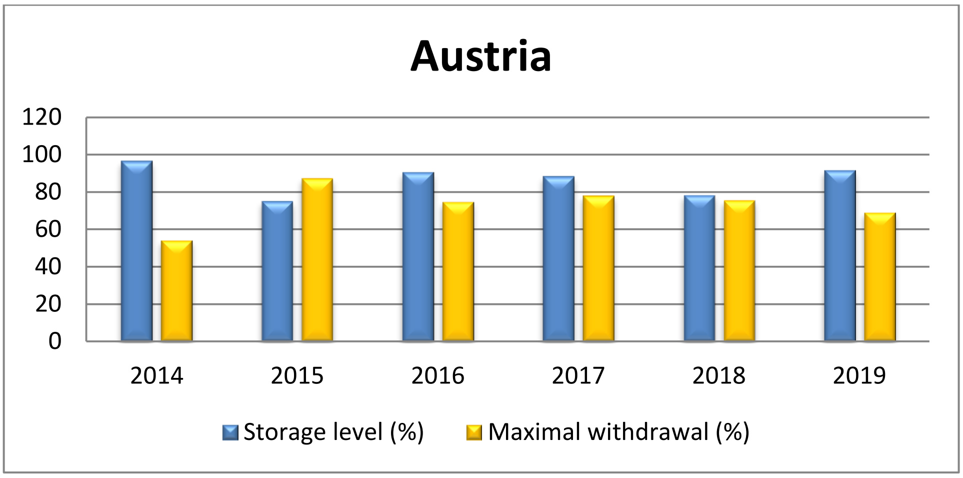
This strategy focuses on cooperation more than any other project concerning this region. Since a one-size-fits all approach will not work here, there are 12 priority areas specified, targeting various sectors such as sustainable energy, tourism, water quality, environmental risks, business competitiveness, security and all rail-road-air-waterways mobility. Not every priority area is important for each country, but the participants have their own key points in the Danube Region. However, cooperation is crucial in achieving the goals this strategy pinpoints. In this study, we focus on the sustainable energy Priority Area (PA2), more specifically on energy storage. There are two main reasons for this. On the one hand, it helps in achieving the national targets based on the Europe 2030 climate and energy targets, along with the National Energy and Climate Plans. On the other hand, it is a fact that the Danube Region is a bottleneck in the energy sector, which must be solved in order to establish a stable and reliable supply of energy. This will certainly entail the inevitable implementation of certain investments and projects.

2.2. Gas storage in the value chain in Danube Region

Gas storage provides insurance-, system- and flexibility value in the gas value chain in this region.

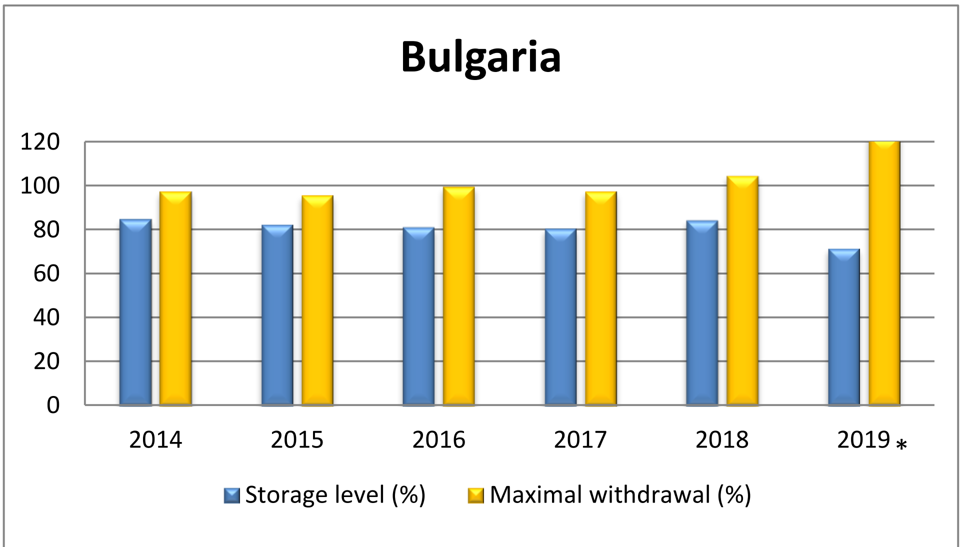
Austria

Austria has a working gas capacity of 9.4 billion m^3. This capacity approximates the country's annual natural gas consumption, in some years, it even exceeds that. Storage sites are owned by 5 companies, the difference in their share is not significant, it is a balanced market. The largest one is OMV Gas Storage, followed by GSA and RAG Energy Storage. The average storage fill-up level in the last 5 years has been at least 80%, and in 2019, their capacity will most probably be filled completely. This trend is expected to continue since market participants must consider the scenario where the Ukrainian transit comes to an end. Austria does not have any plans at the moment for increasing their gas storage capacities.



Bulgaria

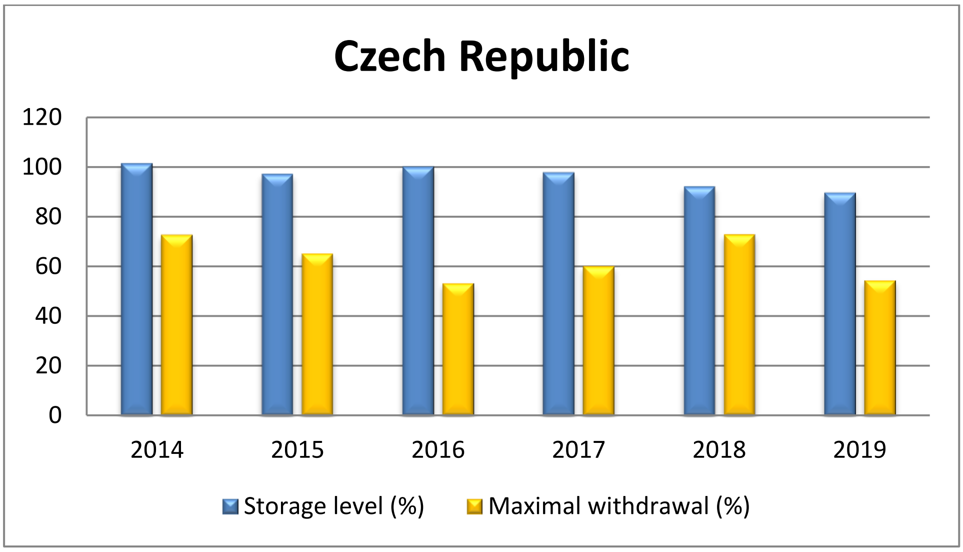
In Bulgaria, there is only one company managing the nation's gas storage sites. The current capacity is 641 million m^3, and they currently have plans to increase their storage capacities by 1.1 billion m^3. Following the expansion, Bulgaria will have trebled its natural gas storage capacity. The country's annual consumption is 3.3 billion m^3, therefore at present it can cover about 20% of its consumption from storage, while later, when the investments are completed, nearly 55% could be provided from storage. Their average fill-up level in the past years has been over 80%, which is due to the fact that Bulgaria has a relatively high demand compared to its storage capacities.



**after expansion of capacity*

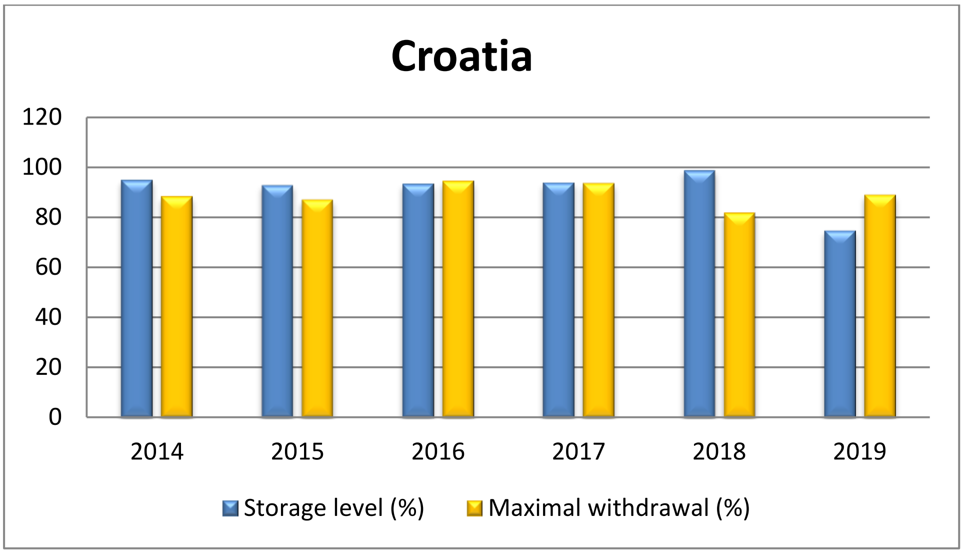
Czech Republic

Total gas storage capacity in the Czech Republic is 4.1 billion m^{3,} of which 2.9 billion m^3 is provided by the gas storage market leader, Innogy Gas Storage. They are currently increasing their capacity by 0.2 billion m^3. In the past 5 years, the stock level of storage sites has been above 90%, in 2014 and 2016 it even reached 100%. If the current trend persists, they will have 100 % in 2019, too. The annual consumption in 2017 was 8.7 billion m^3, which means they can store up to 47% of their annual consumption.



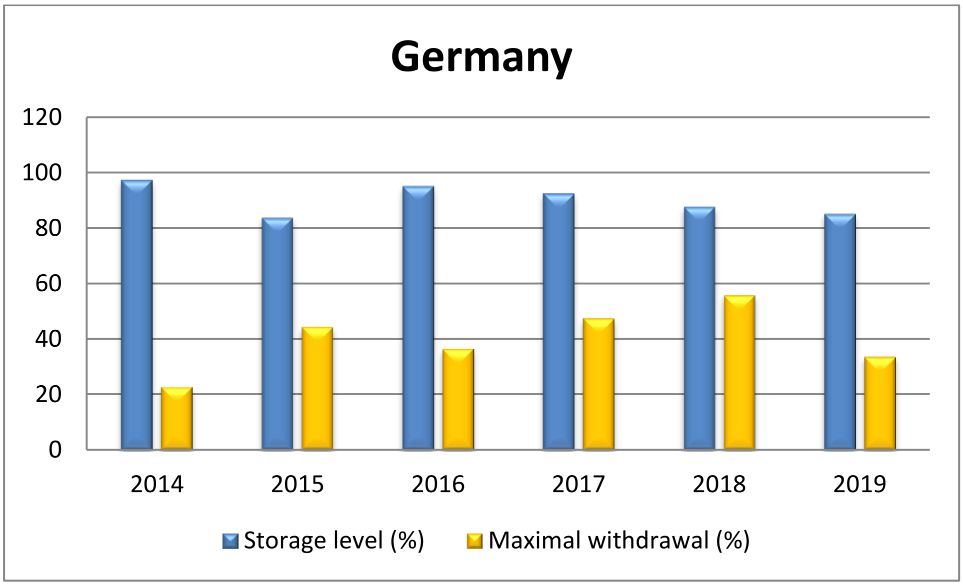
Croatia

Croatia has one company operating in the storage market with a working gas capacity of 594 million m^3, while there is an expansion of 60 million m^3 capacity being contemplated. In the past 5 years, the storage level has been above 90%, which is due to the fact that the annual consumption is 3 billion m^3, being five times the total storage capacity. Any further significant expansion of storage capacity cannot be expected. In the future, supply is planned to be carried out through the Krk LNG terminal. However, the commercial phase of the terminal is not likely to start before 2022.



Germany

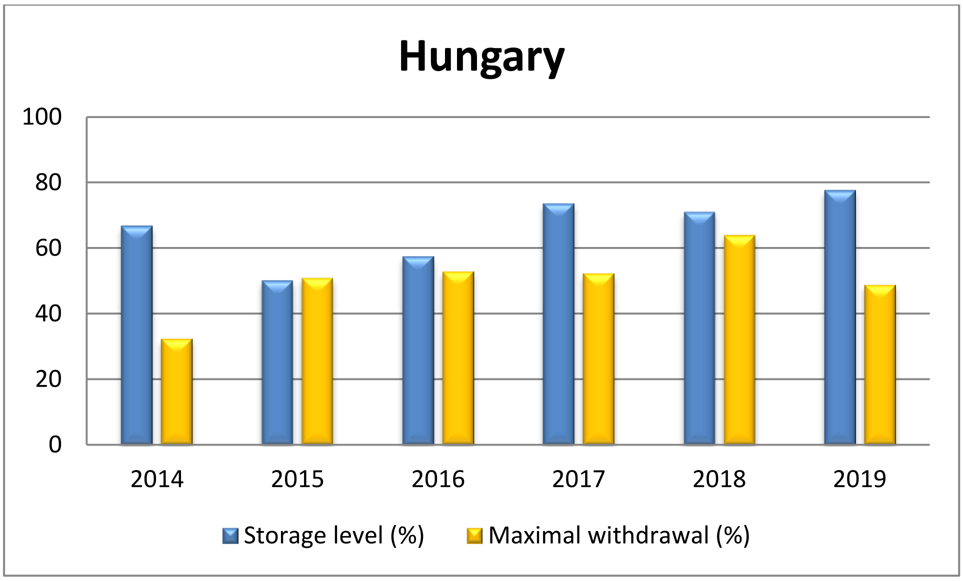
In Germany, there is a proliferation of companies in the gas storage sector, where the largest ones are Astora and Uniper Energy Storage. The total storage capacity is 26.7 billion m^3, with a planned expansion of 935 million m^3. Their annual consumption was 95 billion m^3 in 2017, which is nearly 4 times their capacity. The storage level has been approximately 85-90% over the past 5 years.



Hungary

Hungary has 5 storage sites shared by two companies with a working gas capacity of 6.3 billion m^3. Depending on the year, this amount covers about 65-70 % of the annual consumption, which is a rather high percentage in the region. However, the security of supply risk is also large due to the high (more than 80 %) import dependency ratio in Hungary, which justifies the necessity of this amount of gas storage. In addition to its insurance value, gas storage plays a leading role in the flexibility market since it contributes to daily consumption with 60-70 %. In order to ensure the hydraulic balance of the system, the storage sites help traders balance their portfolio by the immediate storage load changes. The relevance of these 3 storage roles were truly demonstrated when in December 2017, due to the Baumgarten explosion, import from Austria to Hungary was significantly reduced, and MFGT made up for the missing resources by intensifying daily withdrawal, thus preventing an extreme peak in the wholesale gas price (in Slovenia and Italy the wholesale gas price hiked tenfold the very same day and the following days). This way, the Hungarian market remained stable as far as supply and price stability were concerned.

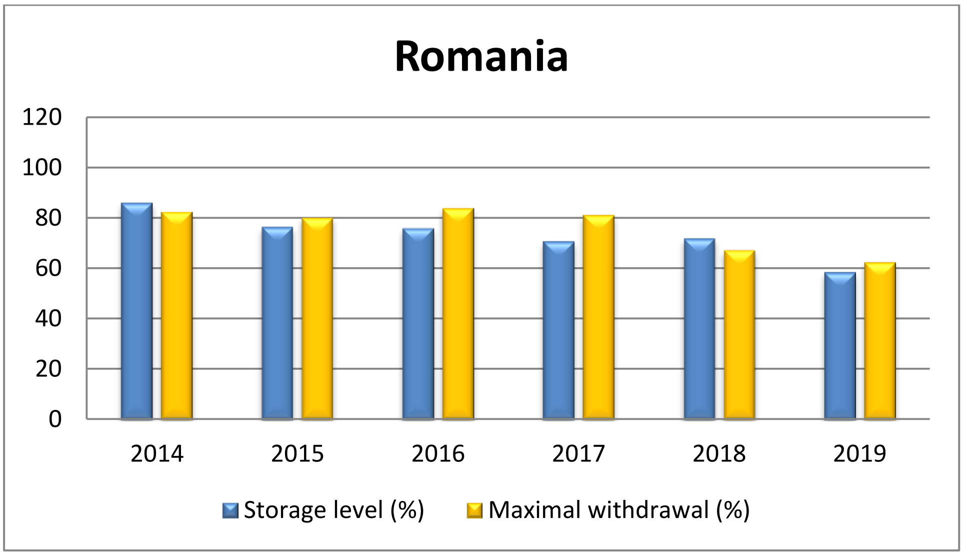
The utilization ratio of storage sites over the past 5 years has been roughly 60-70 %, but as of April 01, 2019 the entire capacity has been booked and intensive injection has commenced. This is a trend which will probably continue in 2020 due to the uncertain future of Ukrainian transit. The closing working gas capacity exceeded the 100 % fill-up level by the end of October.



Romania

Romania has a total working gas capacity of 3.4 billion $m^{3,}$ owned by two market players, and there is also an ongoing plan of expansion by 1.2 billion m^3. Following the increase, the capacity of 4.6 billion

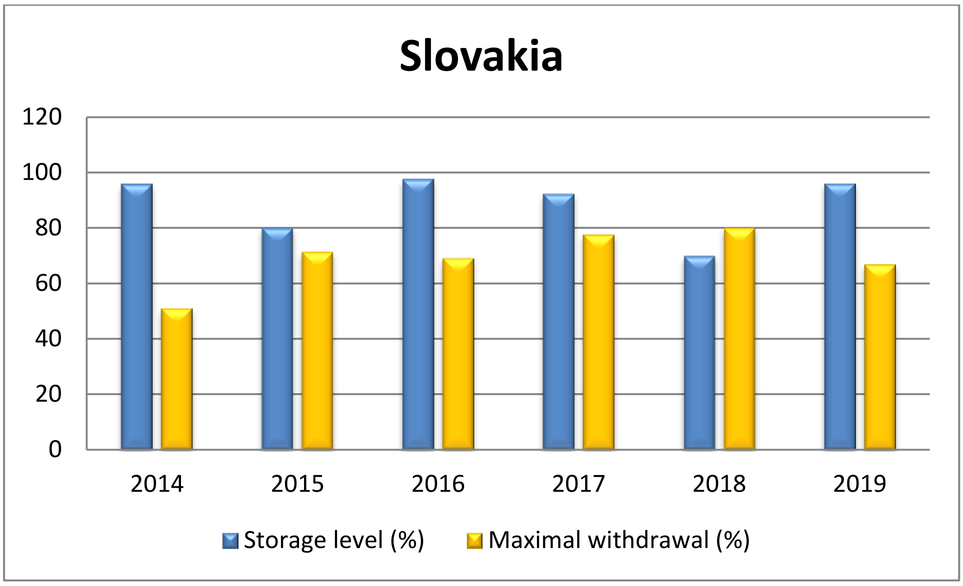
m^3 would satisfy 40% of Romania's total consumption, which was 12.6 billion m^3 in 2016[8]. Regarding the gas storage level, it is relatively low compared to that of the other countries: 70-75% on average in the past 5 years. This figure is rather low, despite the fact that they consume a lot of gas, and they are mainly dependent on imports. In the future, sources in the Black Sea could become a core asset to strengthen Romania's position, establishing and maintaining the country's energy security.



Slovakia

Slovakia's gas storage capacity is 3.6 billion m^3, nearly as high as its annual consumption of 4.9 billion m^3. With the upcoming increase by 369 million m^3, gas storages sites could store up to 81% of the annual consumption, which is a significantly high in the region considering that Slovakia has a considerable transit role. The storage level has been over 85% in the past 5 years, and this year they are likely to achieve 100% of their capacity.

[8] The Outlook for natural gas in Romania and proposals for its value-added capitalization. Vasile Igua, Radu Dudau, June 2018.
https://www.enpg.ro/wp-content/uploads/2018/07/Iuga-Dudau_Natural-Gas_Final.pdf accessed 23.09.2019



Slovenia

Slovenia does not have any gas storage field; their gas demand is about 900 million m^3 and they have interconnections with Austria, Italy and Croatia. Therefore we can say that Slovenia is a well interconnected country, however, they largely depend on neighbouring countries, making Slovenia vulnerable regarding their security of supply. Just an example demonstrating this: in December 2017, due to the Baumgarten explosion, when the Austrian import stopped, the price of gas multiplied in Slovenia as they have no gas in stock.

Bosnia and Herzegovina

The annual consumption is 245 million m^3 and they do not have any gas storage sites either.

Montenegro

Montenegro does not have any gas storage capacities.

Moldova

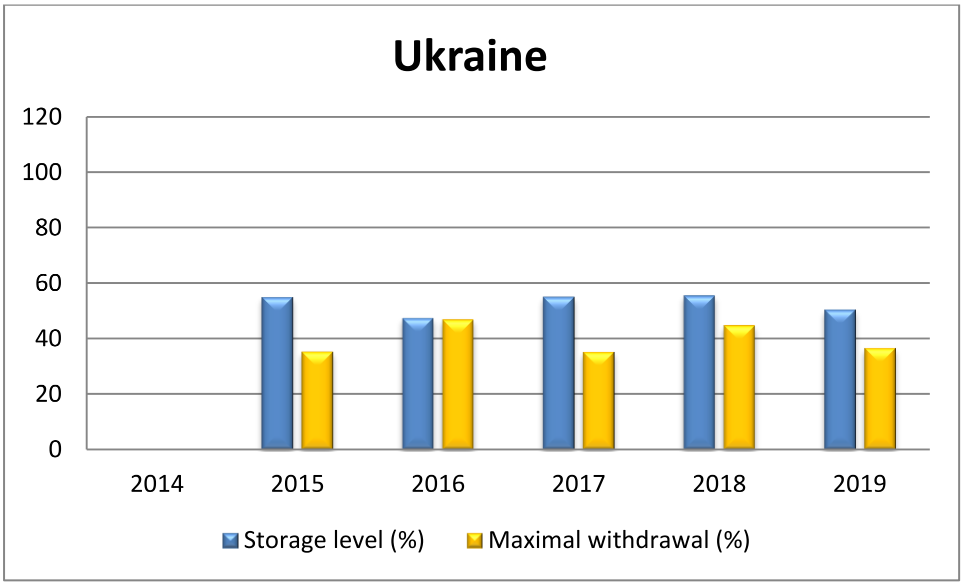
Moldova does not have any gas storages sites.

Serbia

Serbia has one company operating on the market, Srbijagas, which currently has 463 million m^3 capacity, and is planning an increase by another 567 million m^3. With this improvement, the whole capacity will be around 1 billion m^3. This could cover 38% of the annual consumption, which was 2.65 billion m^3 in 2017.

Ukraine

Ukraine has a capacity of 34.1 billion m^3, and the country's annual consumption is 31 billion m^3, but the storage level of storage sites is circa 50%. Ukrainian storage facilities provided flexibility for the transit crossing the country in the past decade. At the same time, due to the Russian-Ukrainian conflict, this transit role has been put at risk, therefore at the moment, they are trying to attract the market players of EU countries into their market.



This section was compiled on the basis of the GIE Storage Database made in 2018. The maximum withdrawal figures rely on the peak days in each year, which are generally in January or February, being relatively close to each other in the different countries. Regarding consumption, our source is the Eurostat, specifically the Supply, transformation and consumption of gas table.

3) OUTLINE OF HYDROGEN STORAGE, CARBON CAPTURE UNITS AND STORAGE (POWER-TO-GAS AND CCUS)

Various alternative solutions are being investigated where underground gas storage will play a major role. The purpose of this section is to give a global overview of these innovative technologies and to illustrate their feasibility with regard to the existing underground gas storage facilities in Hungary.

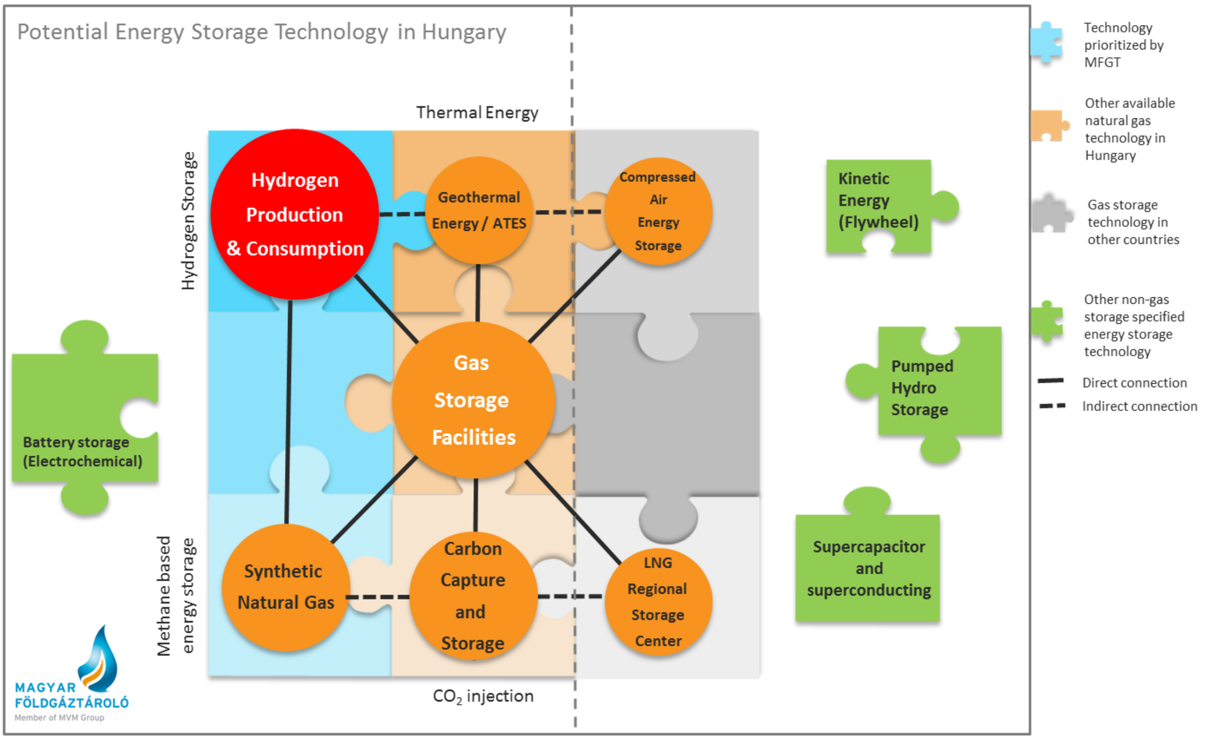


Figure 6: Potential Energy Storage Technology in Hungary (Source: own elaboration)

Geothermal Energy does not belong directly to traditional Energy Storage methods, but as thermal resource, it is widely used in Hungary (and ATES, as an Energy Storage method would be important role in the near future). The utilization of geothermal energy could play an increasing role in the security of primary energy supply during the decarbonisation process. Our Underground Gas Storage Sites are located in areas with relatively high geothermal potential; with estimated usable water temperature around 70-85°C. Possibilities for utilization include district heating, agriculture and industrial (electricity generation, cold storage, drying). On the other hand, our reservoirs have low water content and the most significant challenge is the relatively large distance to nearby cities. Hence, geothermal utilization has not yet become a cost-efficient way for energy storage.

Compressed Air Energy Storage (CAES) is in essence a technology where excess electricity is used to drive compressors in adiabatic, diabatic or isotherm way. When electricity production is at peak, compressed high-pressure air will be injected into the underground gas layers to balance the grid. Compressed air then drives turbines and generates electricity during the withdrawal period. The heat content of the air may be utilized through heat exchangers. All in all, versatility is the main advantage of CAES technology. The disadvantage is that hydrocarbons must be separated from compressed air. In addition, it may react with the reservoir minerals, resulting in acid formation and causing corrosion.

A number of measures have been taken to reduce carbon footprint. The most widespread technology is **Carbon Capture and Storage (CCS)**. In the process of Carbon dioxide capture and storage, underground gas storage would be the last stage in CO_2 chain. The first step is to remove carbon dioxide physically or chemically from the concentrated point of release (for example combustion product of thermal power plants). Currently, there are three different approaches available:

- Post-combustion
- Pre-combustion
- Oxygen-combustion

These are extremely energy-intensive procedures (where the additional energy demand is 10-40 %, while the maximum separation efficiency is 80 percent regarding the produced exhaust gases). The by-product of the gas (or coal) transformation process is carbon dioxide during the production of hydrogen. These two methods can be combined in one step. Produced green hydrogen – as blue fuel using excess electricity – can be then used to balance the grid and store generated carbon dioxide in underground layers. In the next step, the captured carbon dioxide is transported (via pressure boosting with compression or compounding) from the source to the storage formation either by pipelines or tanker ships. CCS projects use pipeline transportation to reduce costs without significantly modifying the existing infrastructure. The third stage is the storage of carbon dioxide in underground reservoirs. The most important criterion is that the reservoir should be able to store high-pressure carbon dioxide without leakage and degradation for up to 10.000 years. CCS technology has a significant carbon reduction potential.

Compared to natural gas, dry carbon dioxide is non-combustible, hence it poses a low risk of backfire or explosion. No special material steel pipes are needed. The implementation of carbon capturing is a mature technology. As tertiary production method, carbon dioxide has been already injected into oil fields to increase the recovery factor (Enhanced Oil Recovery), therefore the know-how of injection is already available.

Injecting carbon dioxide into existing gas storages containing hydrocarbon gas is not recommended, because it will mix with the original gas, significantly reducing the energy content and usability of the hydrocarbon gas. Instead, fully depleted, abandoned gas fields/layers are recommended to that effect.

If free water is present in the system, corrosion will increase as carbonic acid may form. Existing technology elements must be replaced with corrosion-resistant internal coating or steel pipes and corrosion inhibitors must be injected into the gas stream to protect metals and minerals.

Carbon dioxide is significantly more soluble in water than natural gas, and for this reason, PVT measurements/calculations and displacement tests are required to determine injection capacities, since excess injection may frac the formation. From the source side, conventional coal-fired power plants are located in significant geographical distances from the underground gas storage. Due to this fact, appropriate system design and the construction of new pipelines are inevitable. Depleted hydrocarbon fields are capable of storing gas at high pressure in the long term, but enriching gas with a high inert content may also result in the degradation of the geological formation. Therefore, a reservoir with an aquifer is more suitable for this purpose, since dissolved carbon dioxide may precipitate to form carbonates, thus increasing the waterproofing effect of the geological formation.

According to MFGT's plan, the structure of well heads and the diameter of the pipelines will be transformed after having calculated the pressure loss and having defined the well-layer cooperation. It will generate additional costs to separate the liquid that precipitates during transportation. The modification of the installed real-time monitoring system should be converted to reduce risk of long-term operation. Pressure and temperature sensors (as well as a seismic sensor) are required in the tubing to measure the phase change.

To summarize, in Europe, challenges caused by Carbon Capture and Storage technologies and challenges for the next generation of carbon dioxide-filled underground storages can be tackled.

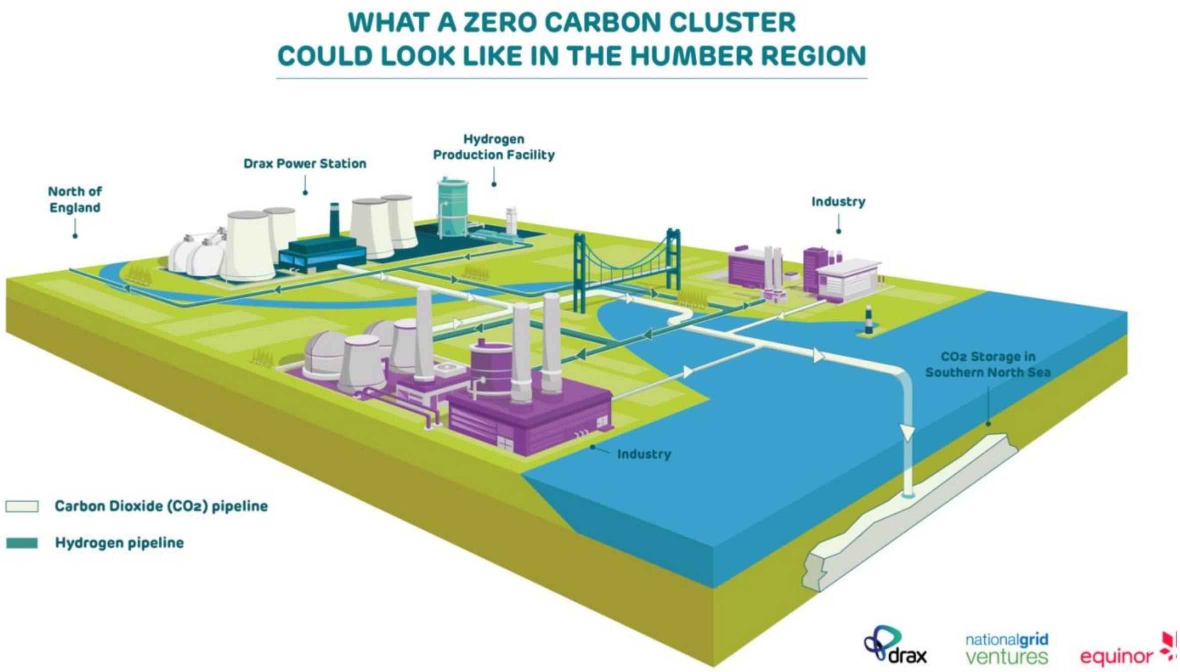


Figure 7: *Carbon Dioxide value chain from sources to storage in the UK* [9]

As outlined in Chapter 1, the scope of this project is **Hydrogen Production and Consumption**. This technology requires less technical adaptation and implementation than other Energy Storage solutions examined under natural gas storage circumstances. Long-term sustainability would be economical if surplus energy is produced by installing renewable sources.

The current natural gas system is designed to meet all the peak requirements:

- Annual – Security of supply, which means injection and withdrawal period alternates cyclically.

[9] https://www.equinor.com/en/how-and-why/sustainability.html accessed 25.09.2019

- Monthly – Interseasonal storage and supply
- Daily – Line pack/ flexible storage capacity
- Hourly – Line pack

3.1. TYPICAL CHARACTERISTICS OF HYDROGEN:

Hydrogen is the most abundant element on Earth, it can be found in many organic compounds, as well as in biomass and in water. Small amounts of molecular hydrogen can sometimes be contained in volcanic gas eruptions and in the upper layers of the atmosphere. In the early 16th century, the first artificial hydrogen production was carried out by reacting metals with acids. In 1766, Henry Cavendish was the first to identify hydrogen gas as a single substance by reacting zinc with hydrogen-chloride. 7 years later, Antoine Lavoisier named this element hydrogen, which means "water-forming" because it burns to clean water vapour. As a molecule, it has excellent conductivity and high diffusion rate and it is classified as one of the gases with the highest specific heat. Considering energy aspects, hydrogen has two outstanding physical properties. First, it is **a versatile energy carrier** with high specific energy density (in MJ/kg). Second, hydrogen is a carbon-free energy carrier with pathways to reduce significantly greenhouse gas emissions. [[10]]

Table 1 summarizes and compares the major physical properties of hydrogen and methane. The most important difference between the two gases is flame velocity. Hydrogen burns about 70 times faster than methane and has a higher burning temperature. This value is important for power and heat industry.

[10] Dunn S, History of Hydrogen. Encyclopaedia of Energy 2004; 241–252.

Table 1 – physical properties of hydrogen and methane

Properties		Hydrogen	Methane
Molecular weight	kg/kmol	2.016	16.043
Density (15°C)	kg/m^3	0.0898	0.718
Specific gravity	-	0.07	0.555
Lower heating value (15°C/15°C)	MJ/m^3	10.223	34.016
	MJ/kg	120	47.13
Higher heating value (15°C/15°C)	MJ/m^3	12.102	37.781
	MJ/kg	141.88	52.21
Flame velocity	cm/s	265	35
Flammability in air	% by vol	4 – 75 %	5 – 15 %
Boiling point	°C	-259.1	-161.5
Flame temperature	°C	1527	1222
Mass diffusivity in air	cm^2/s	0.61	0.16

The key characteristics of hydrogen:

- commonly found in compounds
- the smallest, lightest molecule
- flammable gas (and burns very fast)
- higher heating value (HHV): ***141.7 MJ/kg , 39.41 kWh/kg***
- flame speed ***2.65 – 3.25 m/s (>10x methane or gasoline)***
- expansion rate higher than that of the natural gas ***(>800)***
- can embrittle steel (research shows that alloying 10-13 % of chromium to steel has an excellent penetration resistance to hydrogen)

Three main aspects must be considered during planning and building design to minimize the impact of risks:

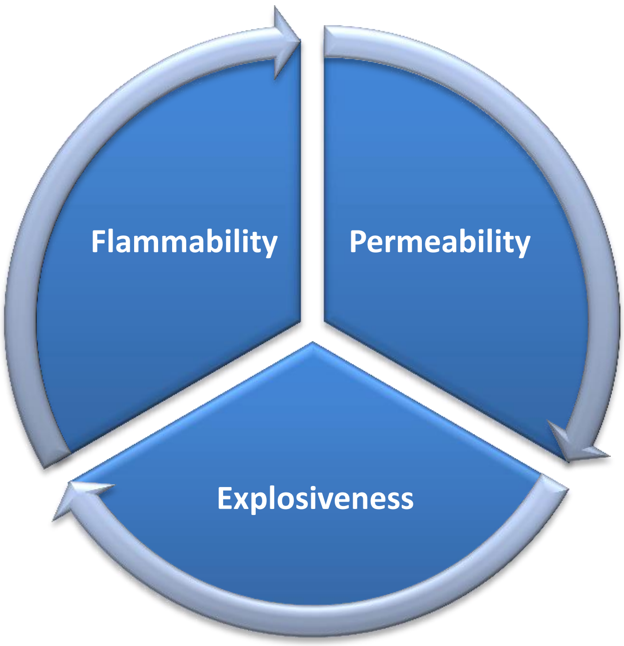


Figure 8: *The triangle of aspects for hydrogen utilization*

Due to chemical reactions, special safety requirements must be considered during design and operation phase. Strict safety rules similar to those regulating gasoline and natural gas must be prescribed.

3.2. HYDROGEN PATHWAYS

Hydrogen is a versatile energy carrier and it can be produced from a wide variety of fossil fuels and renewable energy sources. Mature technologies are the following:

- **Electrochemical:** by electrolysis process to decompose water into hydrogen and oxygen
- **Thermochemical:** fossil fuel feedstock. Producing clean hydrogen must be accompanied by Carbon Capture Storage process

Sustainable hydrogen production process pathways are the following:

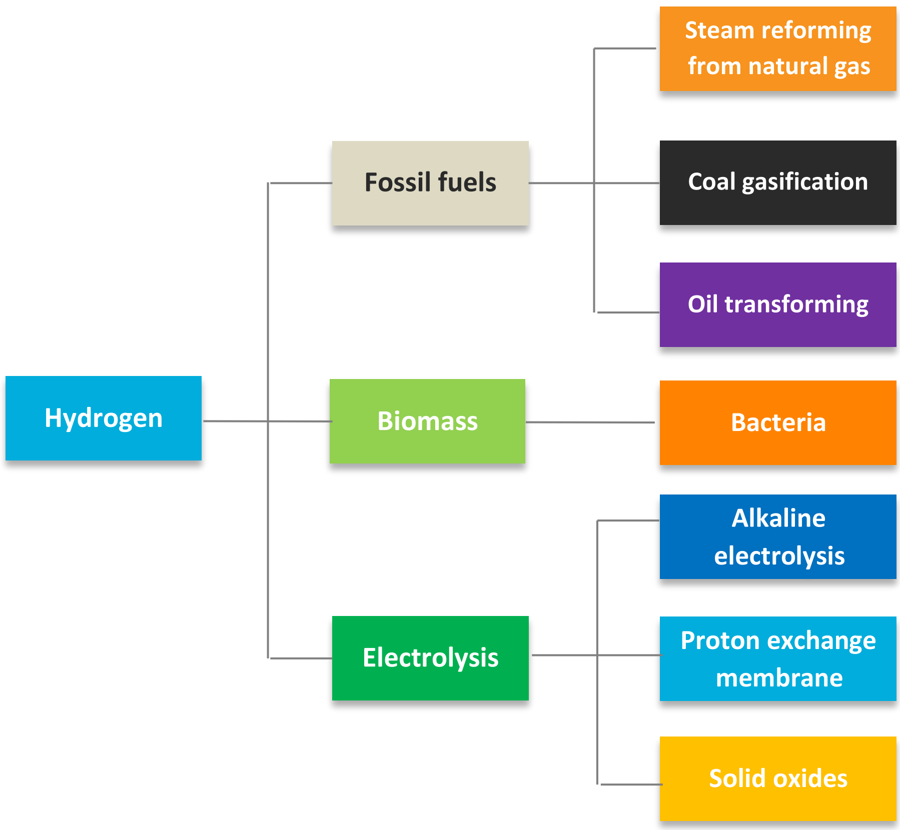


Figure 9: *Hydrogen production pathways*

In a pragmatic approach, we distinguish between blue hydrogen (depending on the energy mix), green hydrogen (direct connection with renewable sources) and grey hydrogen (mainly produced from fossil fuels). In another classification approach, we also get orange hydrogen (where the main source is biomass via biological or photosynthetic process).

Global hydrogen distribution (by sources) is depicted below:

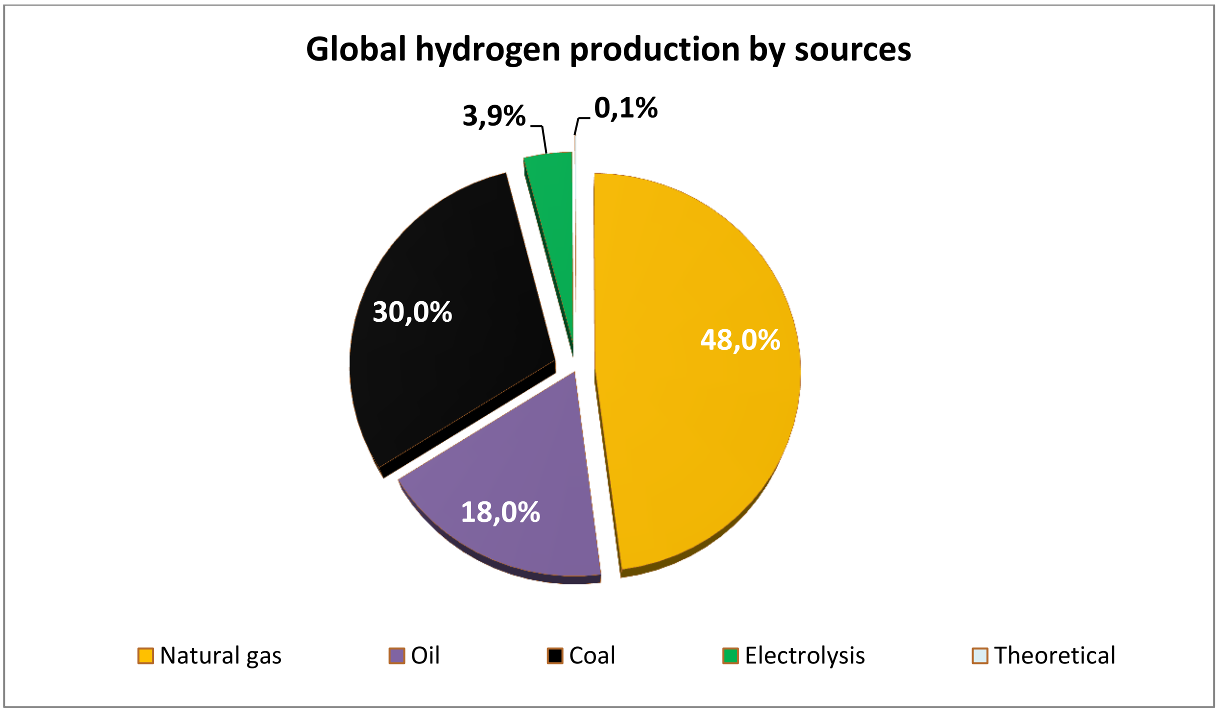


Figure 10: *Hydrogen production by sources* [11]

Main hydrogen sources include steam methane reforming (SMR) from natural gas (48 %). SMR is an endothermic conversion process with an operating temperature of about 850 °C. The production rate of a typical large-scale unit is from 30.000 to 100.000 Nm^3/h. The by-product of the SMR process is carbon dioxide and without CCS-technology, the environmental impact is a rather high.

Where possible, hydrogen is a long-term solution in the natural gas grid and this energy carrier is the pathfinder for the decarbonisation objective. However, enriching natural gas is a possible way to

[11] NATIONAL RESEARCH COUNCIL AND NATIONAL ACADEMY OF ENGINEERING OF THE NATIONAL ACADEMIES, THE HYDROGEN ECONOMY, Chapter 7, The Hydrogen Economy Opportunities, Costs, Barriers, and R&D Needs (2004)

reduce carbon-dioxide emission ***without significantly upgrading*** the existing infrastructure. To fully replace natural gas will nonetheless require the change/modification of consumer appliances. Due to the climate agreement, energy companies are under pressure to reduce emissions in mobility, in industrial and in household sectors.

We have investigated 2 main possible pathways for the hydrogen economy, depending on the orientation aspects.

Bottom-up approach:

- Well-planned concept for the energy storage process is required
- Local synergies to minimize transport costs (step-by-step modelling). Geographical distances between producers and consumer sectors must be taken into consideration due to the decentralized infrastructure
- Establishing a local hydrogen value chain and its integration across different sectors and applications
- Start design with local hubs on dedicated sections
- Analyse the impact of the seasonal storage system
- Using hydrogen and carbon-dioxide in the methanization step will produce synthetic natural gas, which is the essential energy vector for green molecules and provides flexibility for consumption
- Additional potentials of chemical industries (hydrogen is a fuel for Ammonia and Methanol production)

Top-down approach:

- Carbon-dioxide reduction requires sector coupling (electricity and gas grid using excess energy)
- Natural gas grid map – Based on withdrawal and production from gas fields, in which there are ideal injection points for enriching natural gas in the grid
- Concept of an interconnected hydrogen-based energy system
- Low energy prices (or storage incentives to balance fluctuating electricity) and high operation hours can provide short-term ROI-index (return of investment)

- Following some pilot projects, a large-scale extension of P2G capacity in Hungary requires joint development with electrical grid operators in highly loaded areas.

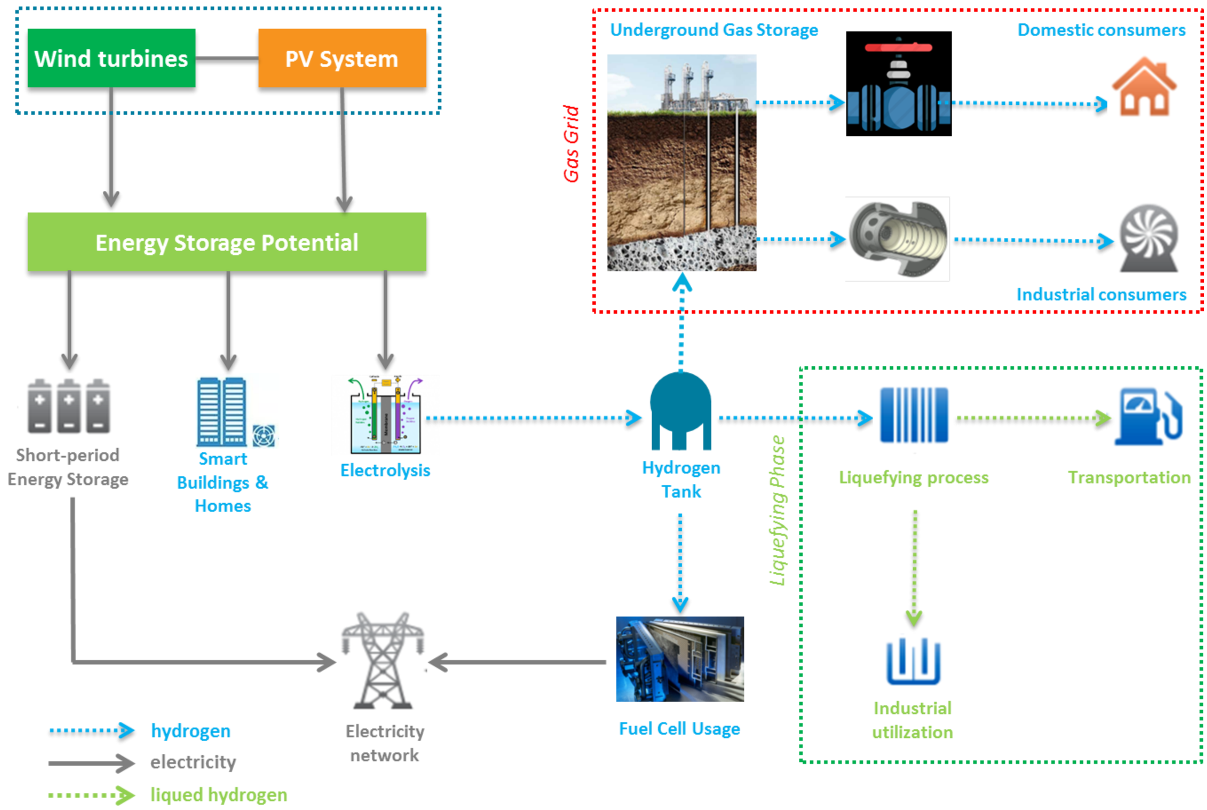


Figure 11: *Hydrogen pathways using gas grid and liquefying process (Source: own elaboration)*

The concept of Hydrogen pathways in Hungary is shown in Figure 11 above. Main energy sources from Photo Voltaic and Wind turbines sector will strongly increase. The most critical point in the spread of renewable energy is how to store fluctuating surplus energy, which has strong weather-dependency. We have examined energy storage methods that are suitable for using off-peak electricity, which we further explain in the next chapter.

Electrolysis is a process of decomposing water (H_2O). This takes place by using Direct Current (DC) to decompose water molecules through a membrane into their elemental atoms of 2 hydrogens and an oxygen.

At commercial level, there are 3 main electrolysis processes, which are currently available:

1. **Alkaline Electrolysis Cell (AEC)** – a widely used technology that typically uses alkaline water solution (mostly potassium hydroxide). [[12]][[13]]
2. **Proton Exchange Membrane (PEM)** – polymer membrane replaces alkaline in a catalytic process. During water decomposition, the generated protons diffuse through a membrane from the anode to the cathode, to connect with neutral hydrogen atoms and create hydrogen gas. The special feature of PEM is that it enables permeation of hydrogen ions but prohibits oxygen to pass through the membrane, thereby preventing the mixture of the produced gases. During the process, water reacts on the anode side to produce oxygen and a positively charged hydrogen ion. Electrons are transferred to the cathode side through an external streaming line while hydrogen ions flow through the membrane (hence the name of proton exchange membrane). After this process hydrogen ions merge with the transferred electrons (at the cathode side) to form a two-atom hydrogen molecule. [[14]][[15]]

   The main differences between AEC and PEM are the following:

   - hydrogen diffuses through a membrane
   - lower operating temperature (80 °C)
   - higher efficiency (65-77 %) – more hydrogen per kWh

[12] Pierre M. and Sergey G.(2013): Water Electrolysis Technologies, in Renewable Hydrogen Technologies, https://www.sciencedirect.com/topics/engineering/alkaline-water-electrolysis accessed 20.09.2019

[13] Mostafa E.S., Shinji K. and Yukio H. (2019): Hydrogen Production Technologies Overview, Journal of Power and Energy engineering, 7 ,107-154 https://www.researchgate.net/publication/330701158_Hydrogen_Production_Technologies_Overview accessed 20.09.2019

[14] SILYZER 200 - High pressure efficiency in the megawatt range (2017) https://assets.new.siemens.com/siemens/assets/public.1524044774.8063d38e3aca74d2a0bcc307fcef435ced002103.silyzer200-broschure-en.pdf accessed 23.08.2019

[15] Radenka M. and Haoran Y.(2018): Nanostructures in Energy Generation, Transmission and Storage, https://www.intechopen.com/books/nanostructures-in-energy-generation-transmission-and-storage/proton-exchange-membrane-water-electrolysis-as-a-promising-technology-for-hydrogen-production-and-en accessed 20.09.2019

- smaller footprint (more kg of hydrogen per m^3 cell)
- devices need low maintenance
- no chemicals are generated during the process
- PEM can work efficiently even when it is not fully utilized, therefore, it could be suitable for balancing of energy peak.

3. **Solid oxides electrolysis cell (SOEC)** – reversible solid oxides cells were developed by the enhancement of hydrogen fuel cells. The system is designed to store electrochemical content using hydrogen pressurization. Due to the extremely high temperature (operating temperature between 700-800 °C) and CAPEX costs, this technology is in research phase. The efficiency of SOEC cells is currently 40 – 60 % [[16]].

On the market, there are Alkaline Electrolysis and PEM Electrolysis available at the moment. Solid Oxides Electrolysis cells are in the development phase. The main benefits of PEM are flexibility, dynamic run-up time, wider load ranges, and higher purity of hydrogen production.

Electrolysis will use off-peak electricity to minimize energy costs and maximize excess energy utilization, therefore it is necessary to set up a real-time communication network to optimize the energy storage system. This interface will start the electrolysis process when peak electricity appears in the grid.

As for Hungarian Gas Storage, there is a real-time monitoring system (called the Plant Information System). This interface connects sensors and the control room, and allows immediate interventions for the operators, who are responsible for the safety process.

One of the most significant challenges of using hydrogen as an energy carrier is the storage of produced hydrogen. There are 3 methods for this:

- Compression: using compressors and pressure vessels. This is the simplest way; hydrogen however has a low storage density (MJ/m^3)

[16] Posdziech O., Schwarze K., Brabandt J – Efficient hydrogen production for industry and electricity storage via high-temperature electrolysis 15.11.2018

- Liquefied: storage of hydrogen in cryogenic phase so the energy density gets higher than in the gas phase(MJ/kg)
- Hydrides: it is a chemical process, where metals blond to hydrogen to form a new compound.

The electrolytic process requires additional equipment to keep the balance of operation over the gas management system as follows:

- Compressors
- Heat exchangers
- Control system
- Pumps and valves
- Buffer storage tank - for technical reasons hydrogen must be stored in proper (and pressurized) storage tanks
- Second stage compressor – additional pressure step to inject the produced hydrogen into the high-pressure gas transmission pipelines

Hydrogen production and consumption produce zero greenhouse gas emissions during operation, but cradle-to-grave life cycle analysis shows a noticeable environmental impact. It means hydrogen-powered devices require special materials and manufacturing throughout the whole cyle. The main emissions are associated with the PEM electrolyser, the hydrogen storage tanks and the electricity powered hydrolysis. Electricity depends on the local energy mix and environmental impact will be reduced with off-peak hours when electricity will be fully produced from a renewable source.

3.3. INNOVATION CLUSTERS

For the natural gas industry, the biggest advantage of hydrogen is that the existing, reliable gas infrastructure which has been in operation for many years now can be modified to be hydrogen-based, thus saving the cost of creating new infrastructure and without having to waste existing infrastructure (as outlined in Chapter 1). As an initial step, hydrogen can be blended with methane and in this way a cleaner gas can be injected into the system, which has a lower level of CO_2 emission. According to current analyses, creating bio-methane will not be sufficient to satisfy consumers' needs, which strengthens the importance of hydrogen. At the same, due to its physical attributes, hydrogen can pose a potential risk. A further advantage of hydrogen is however that it can be applied very well in the transportation, industrial and energy sectors. Thus we can say that in a decarbonized energy system hydrogen could serve as a basic pillar.

Nowadays, more and more nations are realize the benefits of hydrogen or other low-carbon gases. Most of them are only focusing on research and development, or pilot projects, but there are some that are making significant progress.

First of all, Japan considers hydrogen the main energy carrier in the future, and currently it is the leading nation when it comes to using hydrogen, focusing research and development thereon. Hydrogen can enhance Japan's energy security and help transforming the economy into a low-carbon one. The Japanese government dedicated an exclusive fund of over EUR 2 billion to pursue hydrogen technologies between 2014- 2019. Seeing this, it is reasonable to assume that after 2019 the trend will continue, and the R&D of hydrogen will not stop. For instance, Japan already has power plants that operate solely based on hydrogen with no natural gas in the blend. There are whole towns and districts that use hydrogen for energy. In addition, in transport, there is a growing trend in fuel cell vehicles, both in the private and public transport sectors.

In the United States, there some plans and ongoing projects with regard to hydrogen. Hydrogen fuel cell vehicles are mostly popular in California, where there are more than 40 hydrogen fuelling stations, and their number is to increase. There are some FCE buses already in use, too. As for hydrogen in the gas grid, there were substantial studies prepared, which showed its feasibility, forecasting that it is likely to be implemented in the future. Hydrogen for Heat study[17] in particular found that it would be possible and beneficial to use hydrogen-enriched natural gas blend. The main problems are the lack of incentives and the current policies that are not addressing hydrogen enough.

In the European Union, England is trying to use hydrogen to its fullest. They currently deployed a pilot project – HyDeploy @ Keele[18] – in which they feed hydrogen into the grid. This project is carried out in a closed area at the Kelee University Campus. It is possible that they will increase the hydrogen up to 20(V/V) % in the grid. In phase two, they will be injecting hydrogen into a public grid in North England. These projects are regulated by the GSMR, regarding gas quality and safety measures, and do not need further legislative amendments. Besides this, in England, there is a growing number of hydrogen-powered vehicles, in public transport (hydrogen fuel cell trains) or the police.

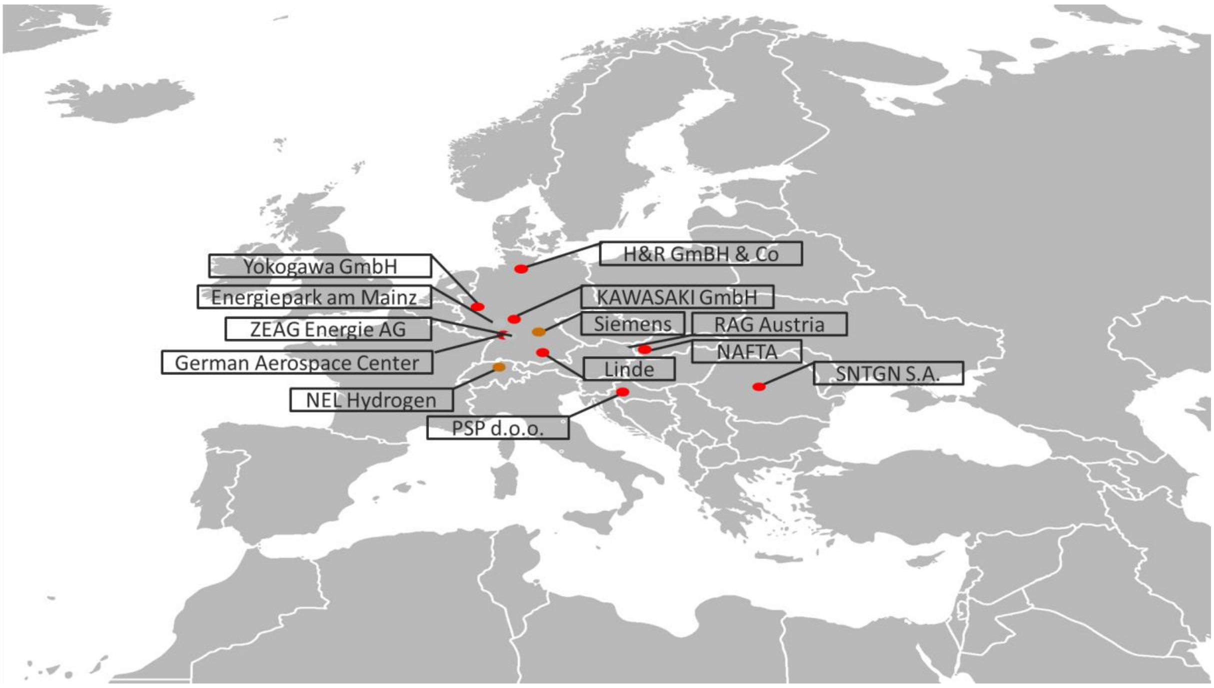
In the Danube Region, Germany is the leading nation in using hydrogen for various purposes. At present, there are 35 power-to-gas plants in operation, with over 30 MW electrolysis capacity, and 16 more are being planned, which will boost the capacity up to 273 MW. In addition to electrolysis, methanization is on the agenda, too. The main usage of low carbon gases is integrating them into the grid, using them in combined heat and power projects and fuel cell vehicle refuelling. However, this low-carbon hydrogen could be used in the steel industry as feed stock, hence the produced steel could be considered low-carbon.

In Austria, besides the power-to-gas facilities, there is a focus on the storage of hydrogen and methane. One of the aims of the projects is to store up to 10% hydrogen with 90% natural gas in the storage sites.[19] The development of hydrogen fuel cell fuelling stations is also contemplated and they are dedicated to significantly increase the share of these vehicles. There is a unique project in Austria where the goal is to develop a stationary electricity storage system with the use of high temperature co-electrolysis and catalytic methanization.

[17] Hydrogen for Heat – Utilizing Hydrogen for Long-Term Energy Storage in Northern Climates, Team Members: Gertrude Villaverde, Jennifer Speaks, Zachary Taie, Zoe Lavrich, 2017.
[18] Hydeploy at Keele accessed 24.10.2019 https://hydeploy.co.uk/keele/
[19] Underground Sun Storage project https://www.underground-sun-storage.at/en.html

It is possible that in the next few years the use of hydrogen will become increasingly popular since the technology is getting cheaper every day and it is a viable solution in the fight against climate change.

Map of potential innovation clusters in the Danube Region:



Upstream: Exploration and Production

Siemens, Erlangen, Germany

NEL Hydrogen, Zurich, Switzerland

Midstream: Storage & Transportation (natural gas pipeline)

RAG Austria, Underground Sun Storage - Austria

ZEAG Energie AG – H2ORIZON Project – Germany

Downstream: Distribution, Refining and End-users

KAWASAKI Gas Turbine Europe GmbH, Hamburg, Germany

Yokogawa GesmbH, Germany

Linde Engineering, München, Germany

EnergiePark am Mainz, Mainz, Germany

H&R GmBH & Co., Hamburg, Germany

Germany Aerospace Center (DLR), Lampoldshausen, Germany

PSP d.o.o. – Croatia

SNTGN Transgaz S.A – Romania

NAFTA, Bratislava - Slovakia

4) POSSIBLE REGULATORY FRAMEWORK ANALYSIS FOR ENERGY STORAGE IN THE DANUBE REGION

The Paris Agreement's [20]main objectives are the following: holding the increase in the global average temperature to below 2 °C above pre-industrial levels, pursue the effort to limit the temperature to 1.5 °C above pre-industrial levels, increase the ability to adapt to the adverse effects of climate change, and make the finance flows consistent with a pathway towards low greenhouse gas emissions. This could be achieved by national contributions of each country who signed the agreement. This was signed by 194 states and the EU, representing 88% of the global greenhouse gas emission. This means that countries like China, United States or India have also ratified this.

However, there are no specifications as to meeting the goals. Fortunately, the European Union has defined the required objectives in order to achieve this. [21]

First, the 2020 goals are: reducing the greenhouse gases by 20% compared to 1990 levels, increasing the share of renewable energy to at least 20% and implementing a minimum 10% increase in interconnectivity regarding the total capacity of the Union. This was published in 2009, way before the 2015 Paris Agreement.

In 2014, new directives were issued for 2030, which are the following: reducing greenhouse gases by 40% compared to 1990, RES increased by 32.5% compared to 1990 levels, energy efficiency increased by 32.5% compared to 1990, and further increasing interconnections to at least 15%. In the European Union each country has a National Energy and Climate Plan, in which they state their contributions. These contributions are similar to the European Union's objectives.

In the long run, the European Union intends to reduce the greenhouse gases by 80-95% compared to the 1990 levels, and there is a dream of achieving net zero greenhouse gas emission by 2050. Therefore we can see that reducing greenhouse gases is the way to fight and mitigate the effects of the climate change.

[20] Paris Agreement, accessed 23.09.2019
https://ec.europa.eu/clima/policies/international/negotiations/paris_en
[21] EU Climate Goals accessed 23.09.2019 https://ec.europa.eu/clima/citizens/eu_en

The first sign of the implementation of the Paris Agreement is that the EU expects the member countries to draft their climate action plans, which will regularly be reviewed and revised if necessary. The following section will provide an overview of the commitments made by the member countries.

Austria

Austria has one of the most detailed and specific action plans to reach their climate targets. A key element of their strategy is that they intend to establish energy network stability through long-term energy storage, while meeting the decarbonisation target, as well. According to the Austrian climate action plan, by the end of 2019, they will have elaborated an action plan focusing on the following points: hydrogen production, greening the energy infrastructure and storage methods, using hydrogen for industry in the building construction sector and as fuel cells in the transportation sector. Green gases, bio-methane and hydrogen will play the major role in future gas supply. At the same time, when constructing new buildings natural gas is still used in order to comply with the regulations. As for regulations, the so-called market premium and investment subsidies are being planned to be introduced. Furthermore, renewable gases will be given a tax allowance.

Bulgaria

Bulgaria seeks to meet the CO2 emission targets by switching from coal to natural gas. By 2030, 25% of the entire energy consumption will be renewable, thus decreasing the emission of greenhouse gases. As for the natural gas market, the diversification of supply routes and sources has received the main focus. Regarding energy storage, Bulgaria is still in the research stage. Research addresses electric vehicles, hydrogen-based technologies and waste-free technologies.

The Czech Republic

They wish to decrease the emission of CO2 by 20 % by 2020 (compared to 2005), and by 30 % by 2030. The electricity generated by natural gas was 8 % in 2016, while by 2040, a 5-15 % use is expected. Their plans could change if the 2020 gas package is released. In order to join the natural gas system, they are planning a financial and institutional support for biogas stations. In addition to this, gas transmission and distribution systems are being modified and prepared for the transportation of new types of gases. Financial support would be granted to projects where energy is to be stored in the form of gas. Aside from hydrogen cell use, the development of gas and steam turbines and LNG transportation are also highlighted research areas. The intention of the legislator is to make the use of electricity produced from renewable sources energy tax-free. They are studying the usability of hydrogen in transportation, the establishment of storage stations and the production of hydrogen-fuelled vehicles. Another possibility under thorough consideration is the storage of energy in pumped-storage hydroelectric plants.

Croatia

Croatia is planning to reduce the emission of greenhouse gasses by 43 % by 2030 compared to the level of 2005. Natural gas and electricity infrastructure is being prepared for the transportation of biogases. As for energy storage, they are considering pumped-storage hydroelectric power plants. On the other hand, the expansion of the capacity of gas storage sites is also being planned. At the same time, the entire gas transportation system is being prepared for a possible future use in the transportation of biogas. Furthermore, Croatians predict an increase in the downstream sector of natural gas and expect the exploitation of new gas fields by 2035. The transport sector will be further greened by alternative fuelled vehicles, most likely by electricity or CNG powered ones.

Hungary

In Hungary, the main objective is to increase the share of renewable energy sources by 20% before 2030, and reduce GHG emission by 40% compared to the level of 1990. In order to achieve this, new low-carbon technologies are supported in sectors where the energy usage and carbon emissions are high. Likewise, there is a heavy focus on an environmentally friendly electricity sector, and the development of electricity storage for the end-user. Considering the increasing share of solar power plants in renewable energy production, the support for electro mobility is in place and increased electricity production is expected in the upcoming years. The diversification of natural gas sources has a focal position in the Climate Action Plan. Diversification can be achieved with the help of the offshore production of Romanian gas fields and the Croatian LNG.

Germany

Germany has a unique place in Europe since it is the largest CO2 producing country in the EU. Their objective is to achieve a 30% share for renewable energy sources in gross electricity consumption by

2030. Natural gas is regarded as a vital in the security of supply, and due to the fact that the CO2 emission of natural gas is roughly half of that of coal, it can also serve as an alternative for coal in electricity generation. The basic pillars of electricity production from renewable sources include solar and wind power. The objective is the further promotion of electro mobility, along with vehicles powered by CNG, LNG or hydrogen fuel cells. To support the spread of alternative fuels, there is a heavy focus on hydrogen-based fuel cell technology, and the use of natural gas as fuel, which could get a tax incentive until 2026 as a regulatory measure. In addition to the above mentioned endeavours, CCU and CCS technologies will be in the focus of research and development.

Romania

Romania intends to increase the share of renewable energy sources in gross electricity consumption to 27.9% before 2030. Solar power plants, wind power plants, as well as pumped-storage hydroelectric plants are seriously being considered. With the increasing numbers of alternative fuels in the transport sector, there is a heavy focus on researching hydrogen fuel cells and lithium-ion battery for storage. At the same time, an increase in the production of oil, natural gas and lignite is planned, together with the expansion of gas storage capacities.

Since gas-to-power technologies have great potentials for the future, hydrogen injection into the existing grid must be prepared.

Slovakia

Slovakia's ambitions are quite low compared to other countries: their goal for renewable energy share in gross electricity consumption is 14% by 2020 and 18% by 2030. Natural gas is considered as a transition-fuel, and hydrogen (and other decarbonized gases) as the main energy source in the future. Regardless of this, the construction of the north-south gas pipeline and the modernization of gas compressor stations have a priority in the plan. The production of hydrogen via electrolysis is planned by nuclear power plants. They expect that the generation of hydrogen will be one of the key elements in the operation of 4^{th} generation nuclear power plants after 2030. Due to the lack of large renewable power, the development of CCU and CCS technologies will be in the forefront of the climate strategy. Besides this, there is an effort to make biofuels more popular and common principally in the transport system.

Slovenia

Slovenia mainly focuses on increasing renewable energy sources up to 27% by 2030, as well as on strengthening the security of gas supply. For renewable energy sources, they primarily rely on solar power plants and biomass. In addition, there are some smaller objectives, electro mobility and vehicles powered by alternative sources: mostly hydrogen, CNG and LNG.

Bosnia and Herzegovina[22]

In Bosnia and Herzegovina there are no clear objectives to achieve, but they are also on their way towards a low carbon economy. There is an intention to use pumped-storage hydroelectric plants of which the country has large capacities. On the other hand, they plan to improve the efficiency of coal power plants by upgrading heat plants. The country is unique in the way that they tend to focus on disaster management and control, and researches on climate and meteorology.

Montenegro[23]

Montenegro, which is not the member of the European Union, does not yet have specified plans to achieve the figures specified for the future. However, they have ambitions to become an electricity exporter. They are currently focusing on pumped-storage hydroelectric plants, and researches are conducted on the implementation of off-shore wind power plants, solar power plants and biomass use. Similarly to Croatia in this region, they are searching for new coal and hydrocarbon sites to use.

[22] Nationally Determined Contributions, accessed 23.09.2019
https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Bosnia-Herzegovina/1/INDC%20Bosnia%20and%20Herzegovina.pdf

[23] SEA of Montenegro's National Climate Change Strategy, September 2015, accessed 23.09.2019
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=18&ved=2ahUKEwjJydCdxubkAhVpwIsKHQf2DGAQFjARegQIBBAC&url=https%3A%2F%2Feuropa.eu%2Fcapacity4dev%2Ffile%2F86283%2Fdownload%3Ftoken%3DRXWgmldp&usg=AOvVaw1TYED2ANPCKyyQDHRC25Jg

Moldova[24]

In this country, the main objective is increasing the share of renewable energy sources in the production of electricity to 20% by 2020. Aside from this, they seek to raise the share of biofuel usage to least 10%, and reduce the emission of greenhouse gases by 25%.

Serbia[25]

In Serbia, the share of renewable energy sources is not expected to rise in the upcoming years. They are going to increase the usage of natural gas and biomass, and upgrade their gas storage sites. Similarly to Bosnia and Herzegovina, Their focus targets disaster control and management.

This section relies on National Energy and Climate Plans as source. Each EU member country has prepared such plans, which are available online.[26]

The above demonstrated action plans clearly prove that regarding the costs, renewable energy sources and innovations required in order to achieve the goals set out in the Paris Agreement are expensive. This implies that a purely market-based operation of the system is not sufficient. In order to establish sustainable financing for these projects, there are several support schemes around the world, but new, not-yet applied regulations could help establish these new technologies. It is therefore of utmost importance that we involve regulatory means in the process as well and facilitate the elaboration of a transparent subsidy system. As countries have different geological and economic characteristics, there is no single silver bullet; tailor-made regulations are required.

Fortunately, there are numerous ways to receive funding, and there are incentives that make investments in the renewable energy and innovation sector more feasible. At national level, the most common **support schemes are the feed-in tariffs, feed-in premiums, green certificates and investment grants.**

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[24]Supporting Moldova's National Climate Change Adaptation Process, December 2017, accessed 23.09.2019 https://www.md.undp.org/content/dam/moldova/docs/ADA_UNDP%20%20REPORT_final_comments%20ADA_UNDP%20responses_Sept%202018_clean.pdf

[25] Climate Vulnerability Assessment Serbia, Belgrade 2012 http://d2ouvy59p0dg6k.cloudfront.net/downloads/cva_srbija_english.pdf

[26] National Energy and Climate Plans, accessed 23.09.2019 https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union/national-energy-climate-plans

1. Feed-in tariffs[27] rely on long-term contracts with renewable energy producers, meaning that they are awarded a higher per-kWh price for more expensive technologies. For example, a wind power or solar power plant would get a lower-kWh price than a tidal power or geothermal power plant, thus reflecting the costs of investment to encourage the development of technologies. This support scheme is independent from the market price, guaranteed for a particular period of time, and has a higher level of cost efficiency due to lower investor risk and higher transparency.
2. Feed-in premiums[28] are much more flexible than feed-in tariffs. They are dependent on the market price, as producers get premium above the market. The premium can be a fixed amount or can depend on a sliding scale. In this scenario, producers make more revenues when the market price is high, but they are running a risk when it is low. This method is much more market friendly, being in line with the liberalized electricity market model of the EU. However, the feeding premium includes the risk of overcompensation, therefore a regular revision is required.
3. Green certificates[29] are issued per 1 MWh of renewable power. In brief, it is the opposite of the emission certificate. It is a tradable commodity demonstrating that certain electricity is generated using renewable energy sources. These certificates are mostly national, therefore unlike emission certificates, their trading or exchanging is not possible right now. However, on an EU scale – where interconnections are rather good --, it has a great potential in the renewable energy sector. For example, revenue could be generated in this system, which could be financed by the EU ETS revenues.
4. Investment grants are currently the most commonly used mechanisms. They are given by the governments to fund new technologies and projects. There is a wide range regarding the funds, due to the fact that these funds can be established in a tailor-made form at national level. Some types of funds can be non-repayable funds, 0% loans or reduced rates on loans.

[27] Feed-in tariff in Hungary, John Szabo, 07.01.2019, accessed 24.09.2019.
http://www.res-legal.eu/search-by-country/hungary/single/s/res-e/t/promotion/aid/feed-in-tariff-10/lastp/143

[28] Feed-in Tariff vs Feed-in Premium, KGDI Law Firm, 6th South East Europe Energy Dialogue, May 2012 accessed 24.09.2019
https://www.iene.gr/6thSEEED/articlefiles/sessionV/Douklias.pdf

[29] Renewable Energy Certificates, United States Environmental Protection Agency
https://www.epa.gov/greenpower/renewable-energy-certificates-recs

Investment grants can finance renewable energy projects either to the full or require contributions from the producers.

In the European Union, feed-in tariffs and feed-in premiums are the currently applied schemes, yet there is a growing tendency in green certificates and investment grants. In addition, some countries introduced tax allowances on renewable energy, but it is limited to a certain degree: for example in Sweden it is up to 30 MWH per year.

Country	Feed-in Tariff	Feed-in Premium	Investment grant	Green Certificates
Austria	✓	✓	✓	
Bulgaria	✓			
Croatia	✓	✓		
Czech Republic	✓	✓		
Germany	✓	✓		
Hungary	✓	✓		
Romania	✓			✓
Slovakia	✓	✓		
Slovenia	✓	✓		
Bosnia and Herzegovina	✓			
Montenegro	✓			
Moldova				
Serbia	✓			
Ukraine	✓			

At an international level, the EU plays a major role in funding renewable energy. There are various funding programs lead by the European Commission and the EU. These include the Cohesion Fund, Connecting Europe Facility program, Horizon 2020, European Regional Development Fund, European Investment Bank, European Fund for Strategic Investments, NER 300 and the European Energy Programme for Recovery. Their main objectives are the funding of energy-related projects that help reducing greenhouse gas emissions, or increase the use of renewable energy. Innovative technologies with the aim of energy storage and carbon capture and storage are of primary importance, too. According to the EU, to achieve the 2020 energy efficiency objectives, around €100 billion per year is required. This means that private investments are necessary in addition to the investments granted by the EU.

In the next few years, there are number of plans which could help with financing renewable energy sources. As soon as we have the 2020 Gas package, it will establish a legal framework for the energy storage, hopefully settling the future for energy storage, CCSU and other innovative technologies. Furthermore, the components of and a sustainable financing for a clean energy mix will have to be determined, as well. In this process, the EU Taxonomy will be the first step and it should provide possible solutions and ideas in order to make different industries greener. An adequately prepared taxonomy provides guidelines to those intending to invest into the renewable energy business.

The lack of foreseeable stable market operation currently poses a significant challenge when presenting the business case behind energy storage projects, as it is difficult to estimate the expected revenues. The values created by the energy storage technology are not normally considered when developing current energy products. According to the *DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources*, for the sake of the integration of renewable energy production, it is important to encourage the use energy storage systems. The Clean Energy Package does not support the ownership of energy storages by the TSO and DSO, as it might distort competition between the energy storages with regulated revenue and those with market-based revenue. The clarification of unbundling rules and the simplification of licensing processes are recommended to promote energy storage technologies. Prior to setting specific regulatory recommendations, it is advisable to observe the evolution of the market and form regulatory directions in parallel thereto.

The other important factor is the increasing CO_2 price/ton. At present, it is around €29-€30/ton, and it reflects an upwards trend. According to the European Investment Bank, it could climb to €40-€80 by 2020, reaching €50-€100 in 2030.[30] However, in Germany, there has been a call for a CO_2 taxation system review, which is expected to succeed. Prices will be much higher than in the EU ETS, which then could be easily adopted by the EU, resulting in an overall CO_2 price/ton increase. Considering the fact that we see the ETS as a weapon to combat climate change, the revenues it generates could

[30]European Investment Bank Lending Policy Draft, 24 July 2019, accessed 24.09.2019
https://www.eib.org/attachments/draft-energy-lending-policy-26-07-19-en.pdf

be channelled into a fund facilitating new and innovative projects in the renewable energy sector. Nevertheless, it requires further and more detailed elaboration.

In the Hydrogen Roadmap Europe, the Fuel Cells and Hydrogen Joint Undertaking suggests that a tax of 1 cent on every litre of gasoline and diesel would easily finance the construction of a basic EU-wide hydrogen refuelling infrastructure.[31] Be as it may, hydrogen usage in end-user transport is still quite the dream, and it requires further research and development, hence channelling this revenue towards the whole renewable energy and more importantly to the energy storage system would be an excellent way of financing. Over 8 billion euros are estimated in only 3 years, which could pay for numerous investments across the European Union.

Since energy storage and related technologies are new, there is no established regulation yet. In the European Union, there are a lot of general sectoral and environmental policies, but they are just scratching the surface. For the most part, they are in line with the climate goals. Apart from that, at national levels, there already are policies with financial incentives. Firstly, in Germany there is the 7[TH] Energy Research Programme of the Federal Government of Germany[32], with heavy focus on hydrogen and electrolysis. This programme is backed by a 7 billion EUR fund, and the Ministry of Transport and digital Infrastructure is financing the projects as well.

The European Regional Development Fund could also provide help in financing investments, with a scope focused on innovation and research, digital agenda, SME-s and low-carbon economy. Energy storage is both an innovative and low-carbon technology. This means that projects on energy storage would most possibly have more priority than other investments that target one category only. For the 2014-2020 timeline, their annual budget is EUR 183 billion, EU wide.

However, unlike the ERDF, the Cohesion Fund[33] is limited to certain countries. With a total allocation of EUR 63.4 billion, it supports trans-European transport networks and energy-related projects, as

[31] Hydrogen Roadmap Europe, FCHJU, January 2019, accessed 24.09.2019 https://fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf
[32] 7th Energy Research Programme, Federal Ministry for Economic Affairs and Energy Public Relations Division, September 2018, accessed 24.09.2019 https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/7th-energy-research-programme-of-the-federal-government.pdf?__blob=publicationFile&v=2
[33] Cohesion Fund, accessed 2019.09.24 https://ec.europa.eu/regional_policy/en/funding/cohesion-fund/

long as they are in line with the climate goals or have a positive effect on public transport. As a conclusion, the cohesion fund, is a viable option for energy technologies and energy storage.

The upcoming EU Innovation and Modernization Fund could be a major alternative in financing projects related to innovative technologies. This fund will use revenues from the Emissions Trading System, and has a starting budget of 10 billion EUR. The first call will possibly start in 2020. The fund will exclusively focus on low-carbon technologies, more importantly on projects that include environmentally safe carbon capture and utilization, and storage of carbon dioxide, innovative renewable energy and energy storage technologies. The initial funding will be 60% of the total investment with the remaining 40% granted on the basis of milestones pre-defined before the whole project is running. In addition, a maintenance funding up to 10 years is also possible. According to the Commission, it is another important feature regarding this fund that it complements other EU funding programs and will not displace other public or private investment.

5) ECONOMIC IMPACT ANALYSIS

The decarbonisation process requires a large number of measures. The most vital points are the phase-out of fossil fuels, mainly coal, oil and gas. However, phasing them all out is not possible immediately. According to the merit order of ENTSO's Ten Year Network Development Plan[34], gas is over coal, since the CO_2 emission of coal burning is circa twofold of that of gas. Despite all the efforts made, if business-as-usual continues, the goal of maintaining the temperature increase below 2C^o will not be achieved. With regard to this, there have been numerous studies and researches made in the energy sector analysing scenarios.

Firstly, there was research published the title of *The role of Trans-European gas infrastructure in the light of 2050 decarbonisation targets*, as ordered by the DG ENER, and written by Trinomics. This study presents three scenarios.

According to the first, strong electrification is envisaged in the consuming sectors across Europe. Relying on this, the 2050 emission target is possible to achieve, but it requires expensive infrastructure investments. This is however rather challenging for the reason that its public acceptance is supposed to be higher than it is currently. The study assumes that there will be a significant improvement in technologies related to electricity usage (vehicles, storage, etc.), yet gas assets will also be inevitable to support the peak power demand in winter. Gas assets are mostly based on hydrogen and renewable methane, thus the CCUS technology is advanced, too.

The second scenario states that synthetic methane will be the leading energy carrier, which will replace petroleum in the transport sector and coal in the power sector. Since it is a CO_2-neutral gas, we could achieve 95% reduction of GHG gases by 2050. This is a fast path towards decarbonisation. Due to the use of methane, gas plays a significant role. On the other hand, even in this scenario, Trinomics sates that the phase-out of natural gas from the grids cannot be carried out overnight, and it will most possibly take place beyond 2050. This requires the reconstruction of the whole gas infrastructure, generating significant financial costs.

[34] TYNDP 2018, Scenario Report, 27 Dec 2018, accessed 2019.09.24 https://www.entsog.eu/sites/default/files/entsog-migration/publications/TYNDP/2018/entsos_tyndp_2018_Final_Scenario_Report.pdf

In the third scenario, the study states that hydrogen will play a strong role in the energy system. A slight but not significant reduction is anticipated in the gas demand in 2050. As was the case with natural gas previously, it will have some share in the gas grid in the long term. In this scenario, the gas grid will require certain major investments, since capacities will be reduced by transporting hydrogen instead of methane. The industry will use hydrogen as feedstock to have "greener products".

All three storylines have a significant share of hydrogen, whether we go for full electrification or for carbon neutral methane usage. Some investments will have to be made regarding the gas infrastructure and some affect the appliances of the end-users. Gas storage sites will be necessary to enhance the flexibility of the system, ensuring a cheap and reliable supply of energy.

To provide another perspective, one must also have a look at another paper commissioned by Zukunft ERDGAS, and developed by Pöyry Management Consulting. This study presents two pathways, one is full electrification and the other one is the use of hydrogen as the main energy carrier, in order to achieve the 2050 climate goals. First, in the all-electric scenario, there are certain risks. As an example, the all-electric scenario in the transport sector is not possible in the near future due to the characteristics of freight vehicles. The other risk of this scenario is the lack of flexibility since nuclear reactors could not be turned off for days, or turned on occasionally. In the second scenario (where hydrogen is used as the main energy source), the power plants are quite flexible due to the use of hydrogen (as seen in Japan). Electric heat pumps require better insulation in the buildings to be economical, which requires more investments by the end-users.

According to certain European manufacturers, the use of hydrogen boilers for heating - both in commercial and residential sectors – is currently under development, which alternative requires only low investment. Contrary to the hydrogen-driven scenario, going full electric requires huge investments in the electricity grid due to significant demand increase. In addition, the current gas infrastructure is capable of using hydrogen with little or no upgrades.

The position of hydrogen is reinforced by the fact that CCS and CCUS technologies are currently facing certain political opposition throughout the world. However, hydrogen is a viable alternative in the world of low-carbon gases. There are 3 methods to produce hydrogen, with electrolysis having the lowest CAPEX cost. The second method, pyrolysis is a rather new technology, which means that it is only in an initial stage and is much more expensive than electrolysis. The third SMR with CCS method has double the costs if compared to electrolysis, not to mention that it is not supported by public. According to Pöyry's paper, the costs will continue to reduce in the future.

All things considered, gaseous fuels – whether its methane, hydrogen or natural gas – will play a significant role in the future. Investments in these technologies must be encouraged and supported, to achieve our 2050 climate goals.

As far as we know, greenhouse gases are among the primary causes of climate change. The main reason for this is that the increase of these gases in turn raises the temperature, too. Thus reducing our emissions to a significantly lower level is a must. In the European Union, we have the EU Emissions Trading System at a supranational level. In substance, it operates by limiting the maximum output of emissions by installations covered by the system. This includes about 11 000 power stations and manufacturing plants. This is the world biggest emissions trading market, which will be the main pillar of achieving the 2030 and 2050 greenhouse gas emission targets. This system covers the power and heat generation sector, and energy-intensive industry sectors like oil refineries, steel works, and production of iron, aluminium, metals, etc. and civil aviation. Since it caps the overall greenhouse gas emissions, companies are obliged to cut their emissions, otherwise they will have to pay the carbon price, which is an incentive for investing in new technologies to reduce emissions. In addition, revenues from circa 5% of the allowances are channelled into a fund which helps establishing low carbon technologies such as: carbon capture and storage, or other projects related to renewable energy generation or storage. Currently it is between 25-30 €/ton, however it is expected to steadily rise in the future.

Besides the EU Emissions Trading System, there are countries which use a national carbon dioxide taxation system. First of all, Sweden has a carbon price of circa 125 114 €/ton price, having it slowly increased since 1991. According to the Government of Sweden, it was relatively easy to implement the system, and it did not burden the authorities and operators. In Switzerland, the carbon tax is near 90 €/ton, but a further increase to 120€ is anticipated by 2020. Little is known about Liechtenstein, but it has implemented a 90€/ton carbon tax, as well. Finland has a tax of 70€/ton, and they set the objective to become carbon-neutral by 2035. At present, Finland holds the presidency of the Council of the EU, hence further tightening on the subject of climate change and carbon-neutrality will come into effect. In Norway, the petroleum sector and domestic aviation is taxed at circa 33€/ton for carbon dioxide, besides the ETS. Taxes in non-ETS sectors are rather different: for example, regarding mineral oil it is 33€/ton, while the total taxes on transportation fuel is between 190 -270€/ton for carbon dioxide. In France, the carbon tax is currently €44/ton, and as set forth by law, it was to increase to €65/ton in 2020 and to €86/ton in 2022. However, after the "Gilets jaunes" protests, they cancelled the raise, and kept the current price.

In autumn 2019, it is anticipated that Germany will have a law that implements carbon tax or an emission trading system. Different actors have different ideas, for example Svenja Schulze, the current Minister of the Environment, Nature Conservation and Nuclear Safety, suggested an initial price of €35/ton for CO_2 which will increase to €180/ton by 2030. Her is idea is that the more expensive petrol, natural gas and heating oil are, the less people use. Relying on this trend, it is reasonable to assume that an increasing number of countries will implement national carbon taxes, setting a rather high price. Taking this a step further: rising national taxes will most possibly increase the EU ETS prices as well, which will make companies either pay more tax or invest in innovative, low-carbon technologies. Otherwise, achieving the 2050 climate targets without an expensive carbon tax is unlikely, since an incentive is required to promote new technologies and implement them in commercial use.

There have been calculations made regarding prices in the future. In their new lending policy, the European Investment Bank implied that they see the prices in 2020 between 40¬-80 EUR/T_{co2} and in 2030 50-100 EUR/TCO2, and in the long run in 2050 between 130-230 EUR.

6) PUBLIC ACCEPTANCE: THE VALUE OF ENERGY STORAGE FOR THE PUBLIC

Since hydrogen has zero greenhouse gas emission, it has a clear value to the public, while it can also contribute to fulfilling the commitments that member states assumed to achieve emission targets.

Nowadays emission, which is a global problem, has two main causes: traffic and industry. For society it means heavy air pollution every day. One of the ways of reducing air pollution would be banning cars, which is obviously impossible. Using a new, green, technology would be a lot more workable solution both for traffic and industry. A good example could be a hydrogen-based technology, which is being investigated by more and more companies and planned to be used in their long-term strategies, thus contributing to cleaner air. By using hydrogen-based and other green technologies, black carbon and emission of industry can be reduced. Analyses have shown that these by-products, apart from their health risks, halve the yield of crops. Looking at the problem globally, we must highlight that due to population increase, these could have a substantially harming effect on society. This is detectable from the following two facts: the yield of crops are decreasing and people making their living from agriculture are facing lower income.[35]

The other important question for society, besides reducing air pollution, is always the price. What price will it take to reduce air pollution through green technologies? Starting from an average product lifecycle, we can see that a new technology generates the highest cost/unit during its introductory phase. This is true for the uptake period of the energy storage technology. At the same time, following the changes required by energy storage technology, the use of the presently available infrastructure could reduce the financial burden on society. As a general principle, we can say that a holistic view of the entire energy system (gas and electricity) is preferred. A holistic view should also be considered both for the security of energy supply and cost efficiency. Using the existing gas infrastructure provides cost effective options in the long term. Inter alia, it offers a solution to seasonal energy storage, plays an important role in transport, and makes the construction of new electricity networks unnecessary, resulting in cost saving and positive externalities. Excluding the

[35] Recent climate and air pollution impacts on Indian agriculture Jennifer Burney and V. Ramanathan PNAS November 18, 2014 111 (46) 16319-16324; first published November 3, 2014 https://doi.org/10.1073/pnas.1317275111

natural gas infrastructure from European and international funding restricts the realization of the abovementioned security of energy supply. It is of utmost importance to provide equal treatment in relation to development of gas and electricity infrastructure.

By now, it is obvious that public opinion is beginning to realize the seriousness of climate change and its possible outcomes that we will have to face if business continues as usual. This is a fact that was established by the Special Eurobarometer report 490: Europeans attitudes on climate change.

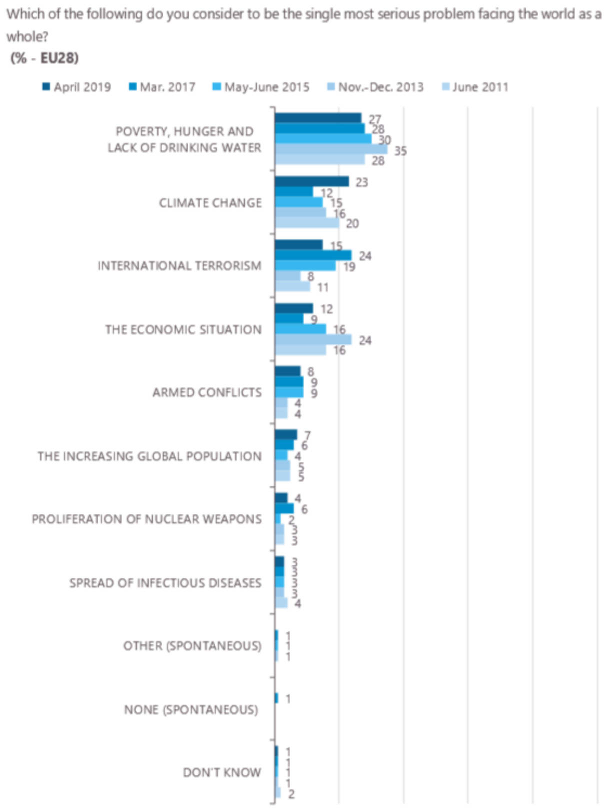

Figure 12: *History of the single most serious problem facing the world (2011-2019) (EUROBAROMETER 490)*

We can see that almost one quarter of the people believe that climate change is the most serious problem. The other main concerns are the poverty, hunger and lack of drinking water and international terrorism. While the concern for poverty, hunger and lack of drinking water are clearly in a declining trend, fear of climate change is growing. It is possible that in the next report this will be the leading concern. The most significant change is the 11-percentage increase from 2017 to 2019 in terms of climate change. In contrast, the concern for armed conflicts and proliferation of nuclear weapons is clearly decreasing.

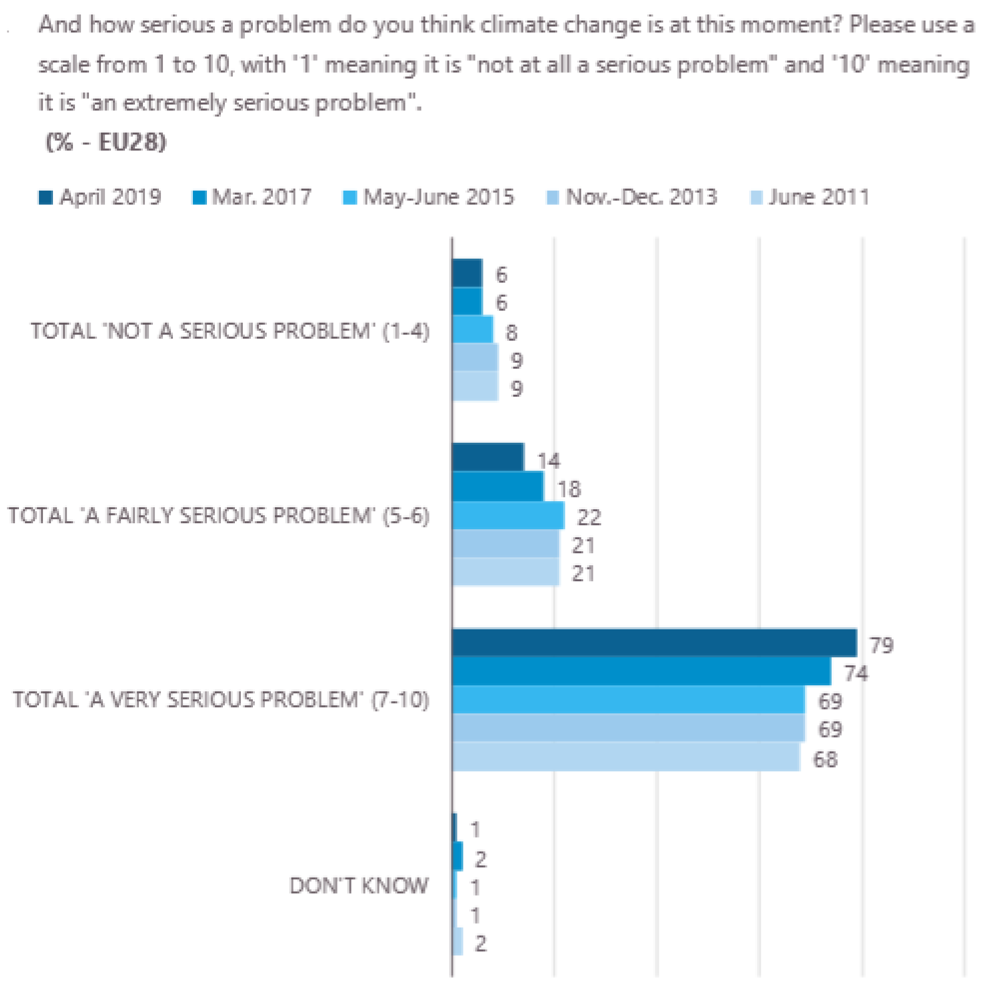

Figure 13: *Attitudes towards climate change (2011-2019) (EUROBAROMETER 490)*

According to this, it is evident that the majority of the respondents think that climate change is a very serious problem, and only 6% say it is not a serious one. All in all, 93% of the people are concerned about climate change. Therefore, upon seeing this data, it is clear why people in the last poll said they support financial incentives even if this means rechanneling subsidies from fossil fuels.

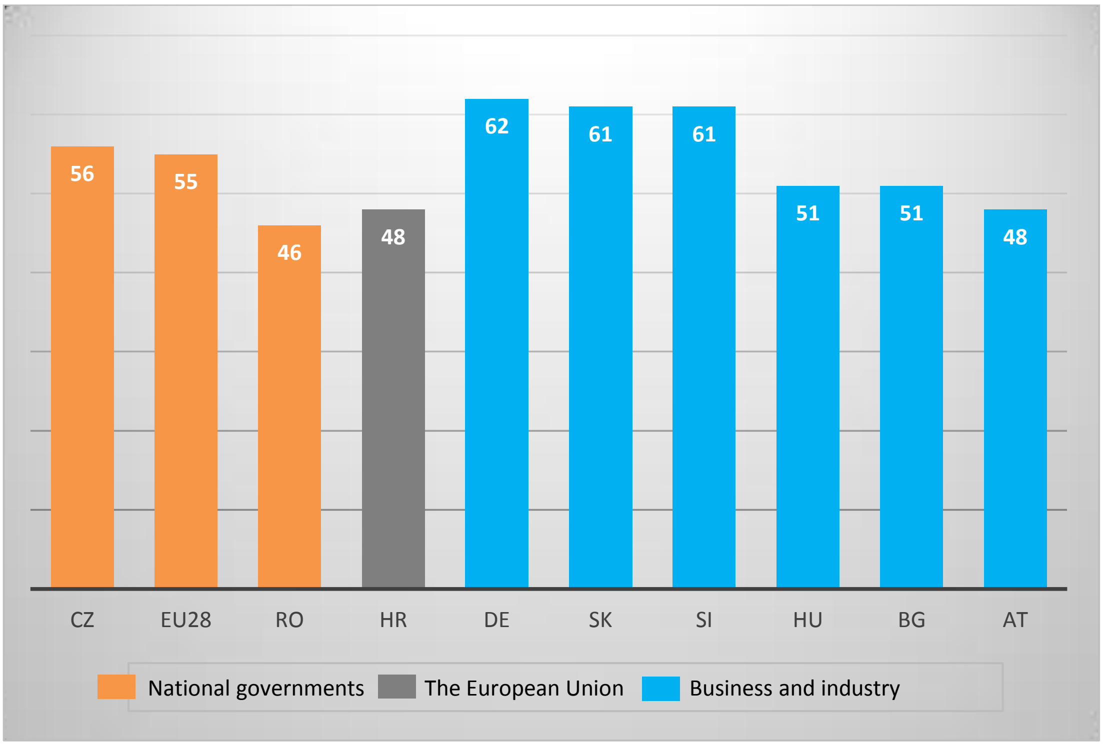

Figure 14: *Approach regarding the responsible sector in climate change*

(Own elaboration from EUROBAROMETER 490)

This table demonstrates that in the Danube Region most of the population thinks that business and industry are responsible for tackling climate change. Only Czech Republic and Romania think that this is a liability for the national governments, and Croatia is alone with their approach that the European Union should be in charge. In this research, there was a fourth option offered, saying we – as individuals – are responsible for combating the climate change, but as far as we can see, the respondents did not agree with that. Thus, after all, business and industry will have to be the main actors, while receiving support – both in funding or incentives and through the regulatory framework – from the government in order to successfully mitigate and adapt to the effects of climate change.

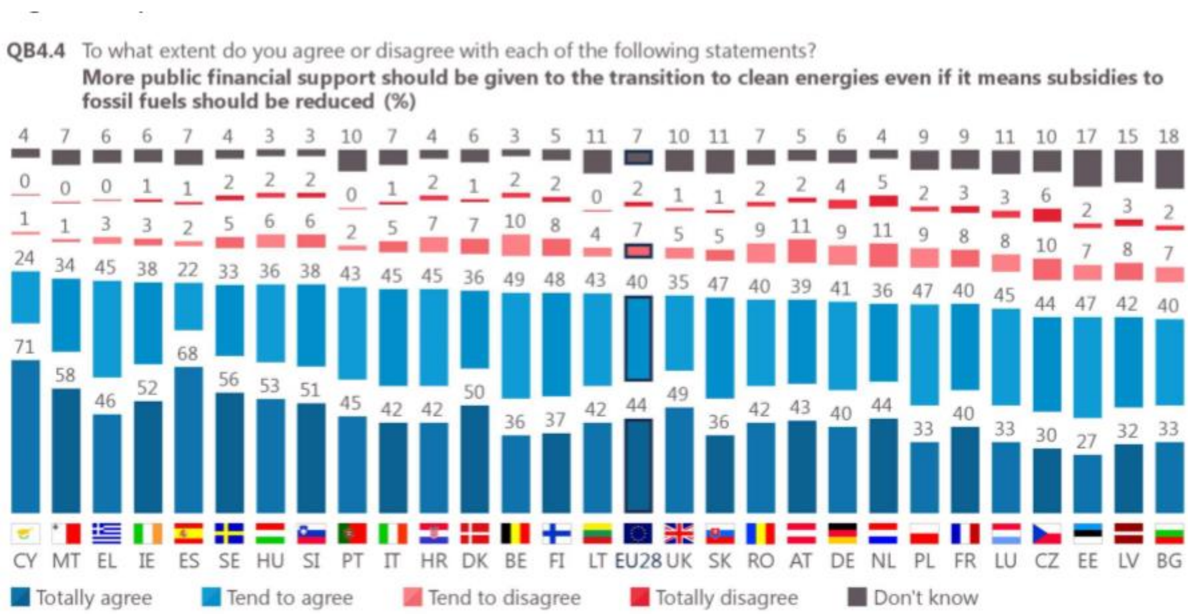

Figure 15: *Poll on financial support to clean energy utilization*

European Union wide 84% people agree with the fact that more public financial support should be given to the transition to clean energies even if that means subsidies to fossil fuels will have to be reduced. Hungary and Slovenia are both first in this in the Danube Region, as 89% of their respondents agree with this. This definitely implies that there is a public support for new clean technologies. This leads back to the table before, demonstrating from where they want the change to originate. So if the public accepts and realizes the value of clean energy with industry and business being the leading actors, national governments should be able to support them to some extent, ensuring each of them achieves their goals as stated in the National Climate and Energy Plan. To be specific, most of the countries are on a way to phase out fossil fuels, starting with coal, so funnelling funds into clean energy technologies would most certainly be helpful and efficient.

The Frontier Economics published a study with the title of *Value of gas infrastructure in a climate neutral Europe.*[36] It states that the existing gas network is fundamental in decarbonisation and benefits the public acceptance of decarbonisation. There are two key points in this section of the study.

- First of all, new electricity lines are quite unpopular with public due to concerns on environmental impacts or health and economic issues. Resulting from this, a lot of the major projects were delayed in the past years. This could cause problems, however, if full electrification is required, since huge investments will have to be made into the electricity grid in little or no time. According Frontier Economics, if we go with full electrification, the electricity demand will be 3 times larger than in 2019. At the same time, gas pipelines are already in place, and can be used to transport energy efficiently without generating further public concern, and require much less space than electricity overhead lines.
- Secondly, they state that gas infrastructure can lessen the pressure on local renewable electricity generation sites. The main reasons are that the gas infrastructure allows us to use:
    - Domestic biomethane, as long as it is based on agricultural waste
    - Imported green hydrogen or synthetic methane from power-to-gas
    - Imported blue hydrogen from natural gas with CSS or CCU technologies

After all, it is evident that utilizing the gas infrastructure with renewable gases, either in storage or energy production is valuable to and supported by the public.

6.1. Safety Overview

Hydrogen technology has a small footprint and will be implemented in safety zones away from built-in, crowded areas. After a design period, it can be easily integrated into the surface infrastructure.

[36] Frontier Economics, The Value of gas infrastructure in a climate-neutral Europe, April 2019 https://www.frontier-economics.com/media/3113/value-of-gas-infrastructure-report.pdf

Using hydrogen as a fuel carrier can reduce industrial and residential carbon-dioxide emissions.

The aspects of health and safety are critical during project planning, installation and operating. There are two ways of installation: the electrolyser and compressor units are fit into shipping containers or into fix, built objects. Comprehensive educational plan is also required for the operators of this new technology. Warning signs will be installed and integrated into a real-time monitoring system so that operators and maintenance staff can check system parameters during operation 24/7.

Low impurity oxygen will be produced as a by-product after the gasification process during electrolysis. This carbon-neutral oxygen would be captured instead of releasing it directly into the environment. This spin-off could be commercialized through an additional liquefaction step.

Furthermore, feasibility studies (and laboratory measurements) are required before using hydrogen in gas transmission and distribution systems.

7) CONCLUSION

The scope of the study is to review energy storage possibilities in general and in the underground gas storage infrastructure. According to Energy Outlooks if the current energy system keeps moving towards a low-carbon one, weather-dependent renewable energy sources and large-scale natural gas storages will play major roles in primer energy system. Energy Storage technologies have great potential as a sustainable, predictable and long-term solution, which will utilize excess electricity, while decreasing emission and satisfying climate targets. This study investigates various solutions for energy storage inter alia Geothermal Energy, Compressed Air ES, Carbon Capture and Sequestration, Hydrogen Storage and Utilization, etc. Hydrogen is a long-term solution and a pathfinder for the decarbonisation objective. Sustainable hydrogen production processes are: steam reforming from natural gas, coal gasification, oil transforming and electrolysis of decomposing water. Enriching natural gas is a possible way to reduce carbon-dioxide emission without significantly upgrading the existing infrastructure. We have investigated possible pathways of hydrogen economy, bottom-up and top-down approaches which are strongly dependent on the final goals to be achieved.

For the natural gas industry, the biggest advantage of hydrogen is that the existing, reliable gas infrastructure, which has been in operation for many years now, can be modified to be hydrogen-based, thus saving the cost of creating a new infrastructure and without having to waste the existing one. At commercial level, there are three available electrolysis technologies and among them PEM-electrolysis is currently suitable for using off-peak electricity and for balancing peak electricity production. The amount of the excess electricity depends on the local energy mix and the environmental impact will be reduced where hydrogen (and synthetic or bio-methane in further stages of improvement) will be fully produced from renewable sources.

We recommend preparing further feasibility studies for the implementation of hydrogen pathways in each segment in the Danube Region in order to investigate the possibilities of using hydrogen as an alternative energy carrier. It would also be advisable to set up common work groups dealing with the technical and regulatory implementation of the new technology. As countries have different geological and economic characteristics, there is not a single silver bullet; tailor-made solutions and regulations are required. This study could serve as a blueprint for the development of hydrogen production and utilization in the Danube Region.

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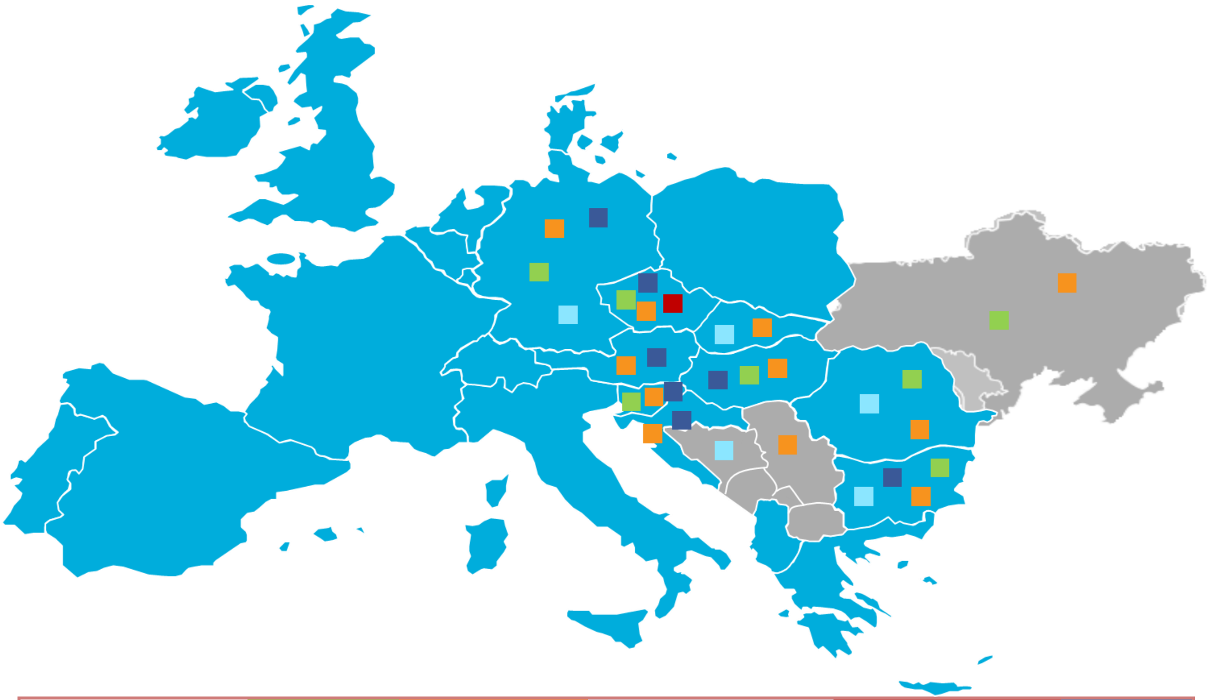
APPENDIX A: Map of underground energy storage methods in the Danube Region (Source: ESTMAP)



	Aquifers	Hydrocarbon reservoirs	Salt formations and caverns	Host rock, caverns, mines	Lakes
Austria		X			X
Bulgaria	X	X	X		X
Czech Republic	X	X		X	X
Croatia		X			X
Germany	X	X	X		X
Hungary	X	X			X
Romania	X	X	X		
Slovakia		X	X		
Slovenia	X	X			X
Bosnia and Herzegovina			X		
Montenegro					
Moldova					
Serbia		X			
Ukraine	X	X			

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