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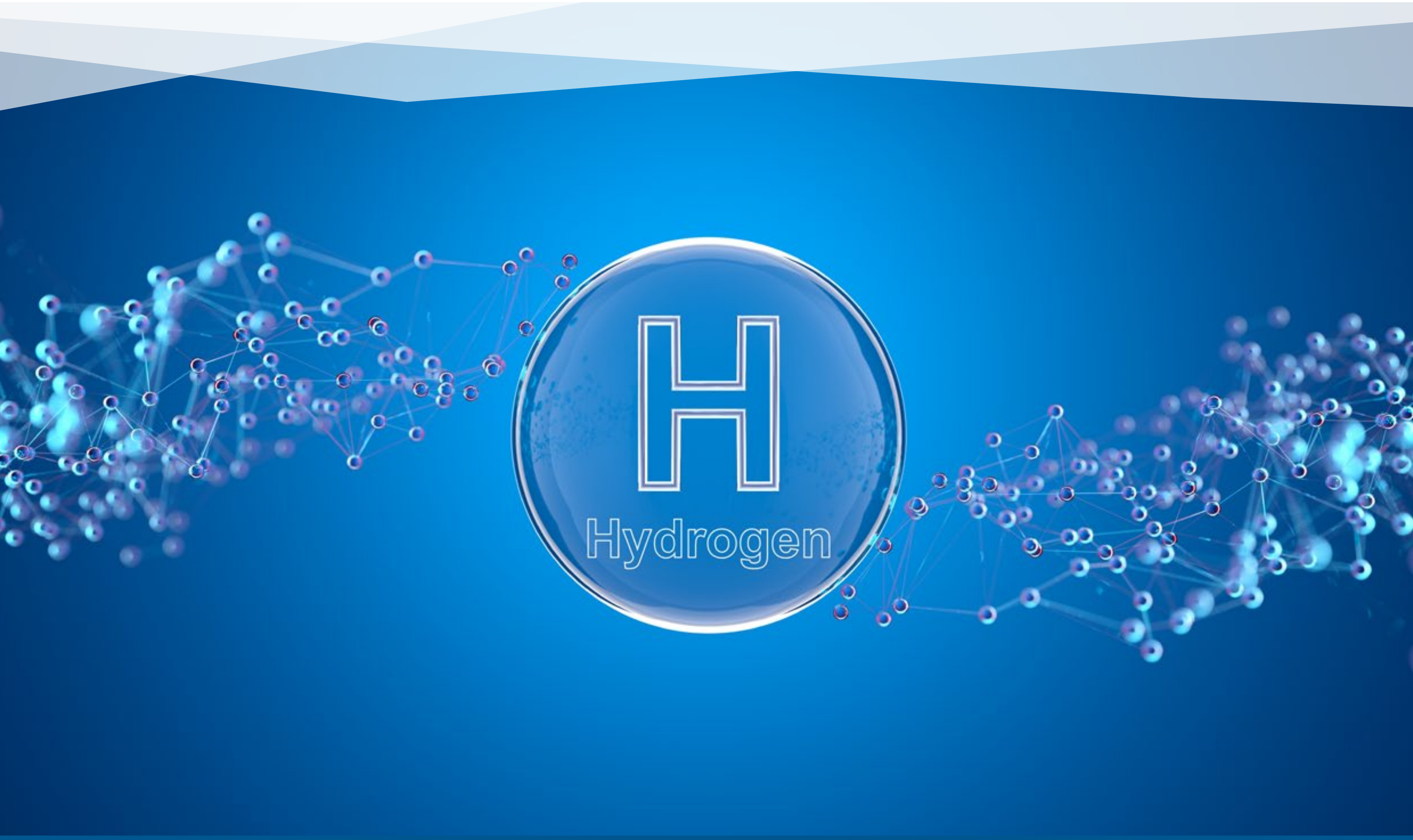

German-Jordanian Water-Hydrogen Dialogue

Relationships between water as a resource and hydrogen production and use

Imprint

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1 | Introduction

This brochure is part of the German-Jordanian Water-Hydrogen Dialogue (GJWHD) funded by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). In addition to the workshops that have been held, this brochure in particular is intended to impart knowledge on the topic to stakeholders who are particularly concerned with water-related issues for a future hydrogen economy.

The immediate context of the project is Jordan's interest in a hydrogen economy against the background of very limited water resources. Since water (H_2O) is needed in particular for electrolysis – as a central process for the global hydrogen economy – a future hydrogen economy in the country can lead to conflicts over the resource intensifying. Accordingly, there is already a need for action and far-sighted commitment today.

The aim of the project is to exchange knowledge on the connections between water as a resource and hydrogen production and use, whereby the country-specific conditions in Jordan and Germany play an important role here. In this context, the focus was particularly on the decentralised hydrogen economy, which also allows hydrogen applications on site.

For the exchange, two workshops were held in Wuppertal (Germany) and Amman (Jordan). In order to shed light on the topic from as many different perspectives as possible, the delegations from Jordan and Germany as well as the speakers were from different stakeholder groups (including the private sector vs. the public sector vs. science; (waste) water vs. the energy industry).
A concept was developed for the content of the workshop, which will be referred to in the following as the water-hydrogen nexus.

Even though the focus was initially on two selected countries, Jordan and Germany, various aspects and contents of this brochure are transferable.

We would like to thank the BMUV for its critical feedback and the active support of the National Organisation for Hydrogen and Fuel Cell Technology (NOW) throughout the project. We would also like to express our gratitude to all delegation participants and speakers in Germany and Jordan for their stimulating inputs and open discussions. They took the time and filled the project with life.

2 | The GJWHD Project – German-Jordanian Water-Hydrogen Dialogue

Jordan and Germany have very different prerequisites for the production and use of green hydrogen. This not only concerns the investment climate, among other things but also the endowment with natural resources. In this context, the availability of renewable electricity and water is particularly important for the production of green electrolysis hydrogen. This is because an electrolyser can only be operated in a sustainable manner using green electricity to break down water (H_2O) into (green) hydrogen (H_2) and oxygen (O_2). Although equally necessary, the sustainable supply of water to electrolysers is less of a priority. As electrolysis will play a central role for the global hydrogen market (IEA, 2022b) this process is also important compared to alternative hydrogen production processes for all countries considering hydrogen production in the future. Accordingly, the current and future resource endowment for electrolysis must be considered with regard to electricity and water.

According to the **Figure 1** there are restrictions on the production of green hydrogen in both Jordan and Germany. These differences are used in the project to complement existing discussions on the topic of hydrogen and to promote exchange between Jordanian and German stakeholders with the aim of creating an understanding of the specific conditions in the respective countries.

While the political and scientific debate on hydrogen production is often driven by the energy or electricity side, it is an important concern of the project to supplement precisely this one-sided perspective with an important point of view. Even though electricity continues to play a central role in electrolysis, the project also tries to work on the topic of hydrogen from the perspective of water as a resource.

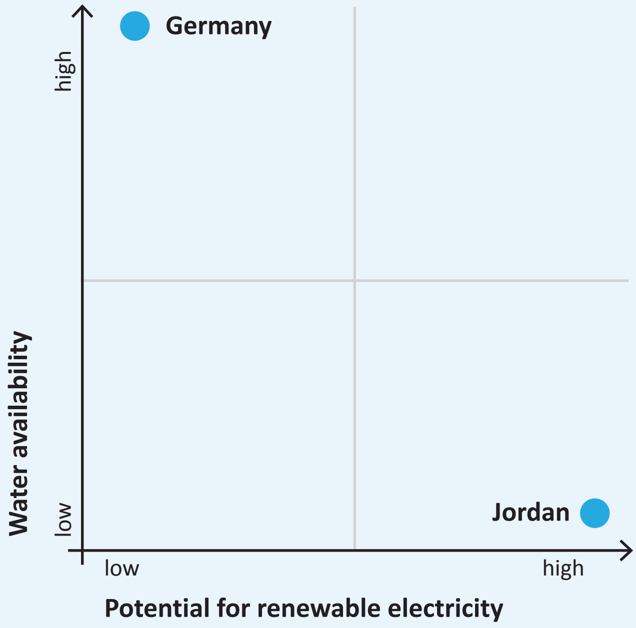

Figure 1
The different starting points in Germany and Jordan as background for the project (own representation)

In addition, the project adds another aspect to the debate. For while Jordan and other MENA[1] countries are repeatedly discussed as important hydrogen exporters for Germany and Europe, the project focuses its attention on the decentralised production and use of hydrogen. Here, many exciting and successful project results are already available in Germany, which can represent solution corridors for other countries. Even if decentralised hydrogen structures are also associated with challenges, there can also be enormous opportunities (e.g. long-term storage of electricity, local reduction of emissions). The exchange of country-specific knowledge relevant to the (development) construction of a hydrogen economy is the overarching goal of the project.

For this exchange, two workshops were organised and implemented as part of the project in autumn 2022 in Wuppertal (Germany) and Amman (Jordan). For the content of the exchange, existing knowledge about the connections between the resource water and hydrogen production (in short: water-hydrogen nexus) was compiled based on literature research. This water-hydrogen nexus was thematically illuminated and discussed from different perspectives.

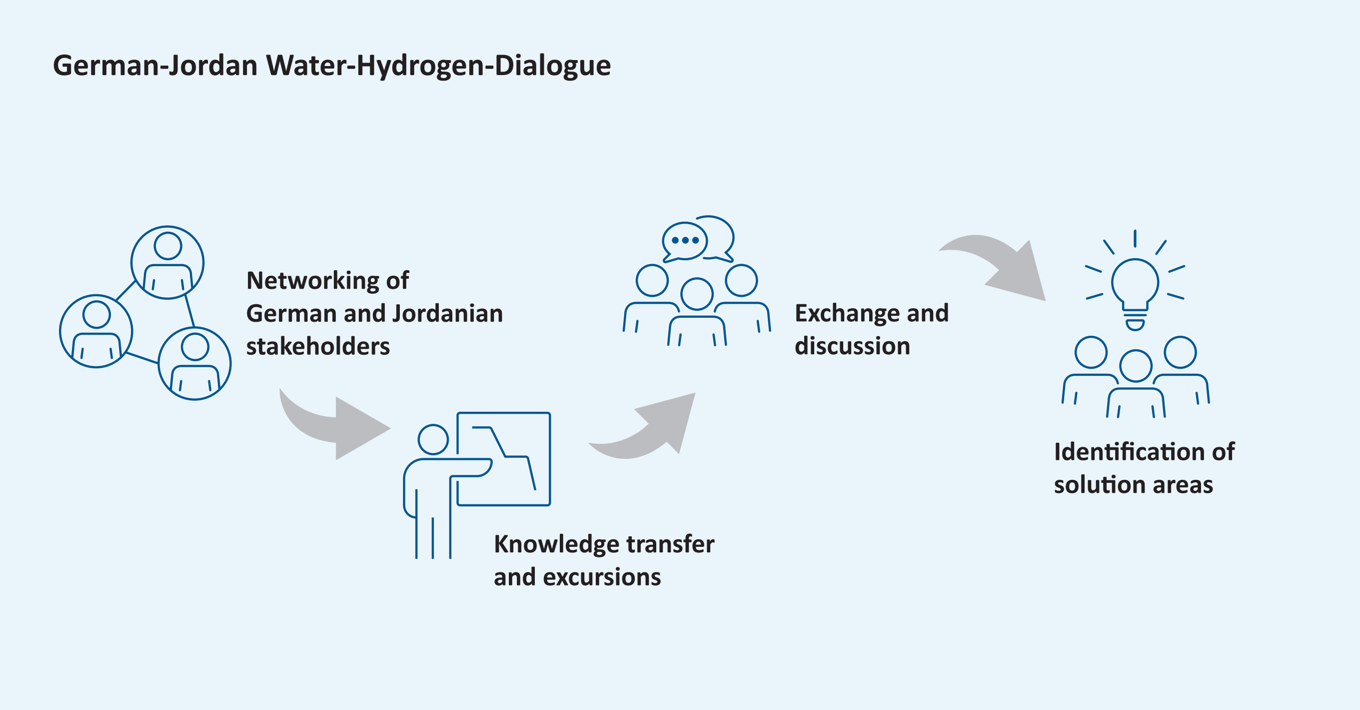

Figure 2
Schematic approach to action in the project (own representation)

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[1] MENA stands for "Middle East and North Africa".

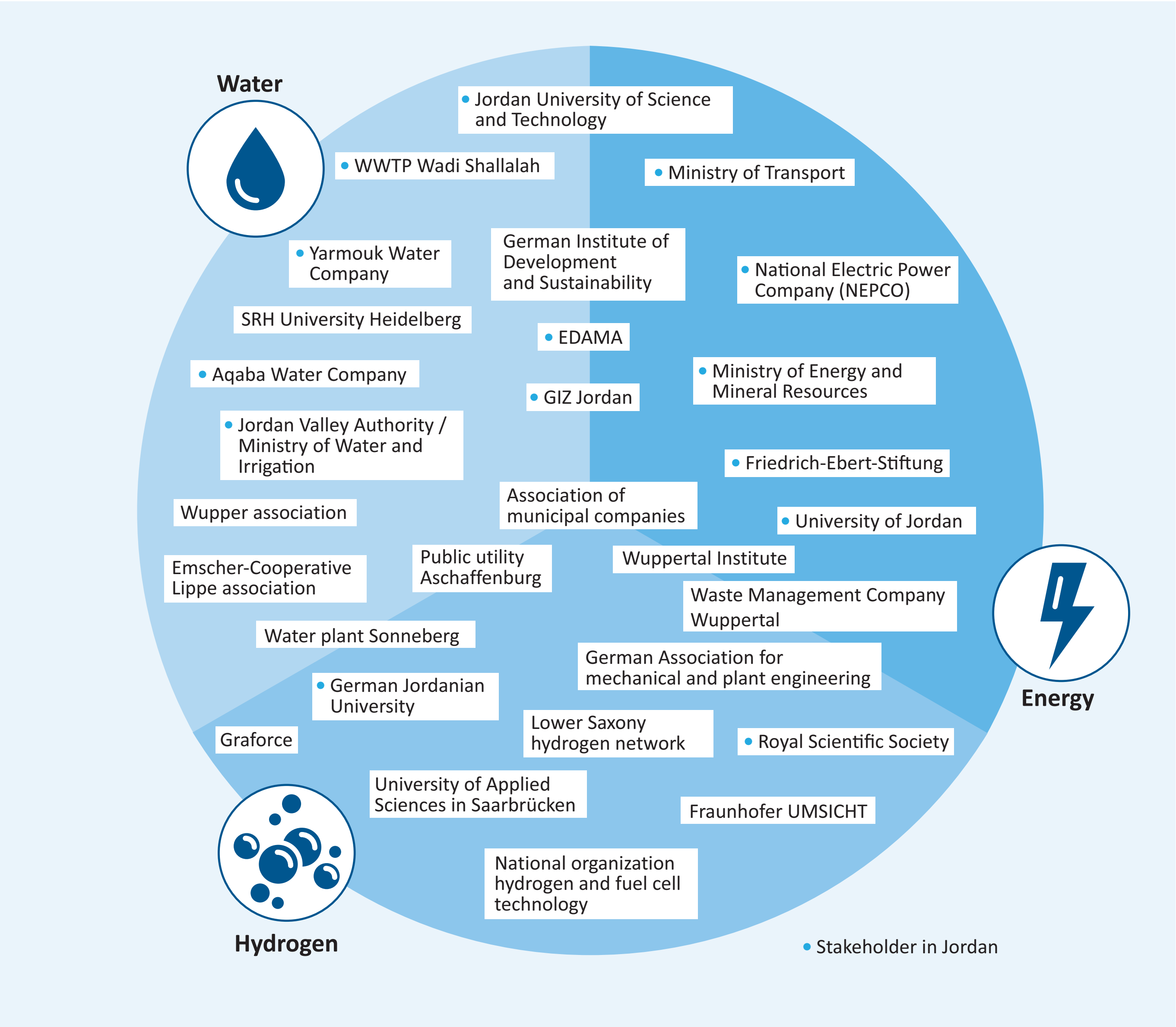

Figure 3
Institutions involved in the project workshops in Wuppertal (Germany) and Amman (Jordan) (own representation)

By conducting the workshops, the results of the literature research on the water-hydrogen nexus could be substantially supplemented. For the preparation and follow-up of the workshops, so-called factsheets were created, which were developed as independent documents. The following two chapters contain these factsheets and combine the results of the literature research with the findings from the workshops in this brochure.

3 | Concept development of the water-hydrogen nexus with focus on Germany

In the following, the concept of the water-hydrogen nexus is derived (Chapters 3.1 to 3.3) and finally presented (Chapter 3.4).

3.1 Central production processes and possible uses of hydrogen

FACTSHEET 1:

Central processes for the production of hydrogen

Current situation

For the production of green hydrogen, electrolyser technologies are at the centre of political debates, as they enable the splitting of water into hydrogen and oxygen. Electrolysers are powered by electricity. Depending on the production method of the electricity, the hydrogen is colour-coded. If the electricity comes from the grid, which in Germany still relies on fossil fuels, hydrogen is considered yellow. For green hydrogen, the electrolysers must be operated with (additional) renewable electricity. There are three central electrolyser technologies that differ in technological maturity, costs and other characteristics (AEL, PEMEL, HTEL).

Hydrogen can also be produced from natural gas by steam reforming or pyrolysis. However, the reforming of natural gas is accompanied by CO_2 emissions. If the emissions are released into the atmosphere, the hydrogen is grey. If a carbon capture plant is connected to the steam reforming plant and the CO_2 is subsequently stored underground, the hydrogen is blue. Pyrolysis of natural gas produces carbon in solid form as a by-product of turquoise hydrogen (MWIDE 2020).

For the integration of fluctuating renewable electricity, PEMEL offers a great future, as this type of electrolyser is the most flexible due to its short start-up times. In contrast, high-temperature electrolysis (HTEL) has very long start-up times, but since it works with high-temperature heat, it can integrate waste heat from industrial processes. Alkaline electrolysis (AEL) has the best overall performance today, especially when renewable energy is less volatile in the respective countries.

Hydrogen can also be processed into other products, for which further synthesis processes are required. Fischer-Tropsch synthesis, for example, enables the production of synthetic paraffin and diesel. For such renewable fuels, however, CO_2 is needed, which can come from direct air capture, from biomass or from industrial plants. Other synthetic products such as ammonia require nitrogen, which generally comes from ambient air (Ausfelder & Dura, 2019).

It is worth noting that there are also technological opportunities for biomass to become part of the hydrogen economy (FVEE, 2021). For waste residues such as sewage sludge, there are thermochemical approaches such as gasification, reforming, methane pyrolysis or hydrothermal conversion. However, the political agenda seems to focus on power-to-X (PtX).

Outlook

The costs for electrolysers are expected to drop significantly. Germany is striving to increase domestic hydrogen production. For example, the National Hydrogen Strategy aims to install 5 GW of electrolysis capacity by 2030.

With the elections at the end of 2021, the target has been doubled. In contrast to the political focus on electrolysers, there is less discussion in Germany about bio-based hydrogen. Given the considerable demand for hydrogen expected in the scenario modelling, Germany will also be dependent on imports of hydrogen and hydrogen-based products (Wuppertal Institute & German Institute for Economic Research Econ, 2020).

Aspects in the Nexus

Hydrogen production through electrolysis in particular, but also other technology paths, require water. For example, the minimum requirement for the production of 1 kg of hydrogen is 8.92 litres of fully demineralised water (Beswick et al., 2021). To obtain this amount of high-purity water, between 15 and 30 litres are needed from public supplies (Energy Sector Management Assistance Program, 2020). Auxiliary technologies may also have water requirements for operation; for solar PV, between 0.01 m^3/MWh to 0.1 m^3/MWh is required for cleaning the modules (Zelt et al., 2021). Pink hydrogen based on nuclear power consumes about 270 kg of cooling water per kg of hydrogen (Hydrogen Council, 2021). Particularly when importing hydrogen from arid regions, attention must be paid to the extent to which local production affects local water management.

FACTSHEET 2:

Hydrogen utilisation possibilities

Current situation

Green hydrogen can play a central role in realising emission savings in various sectors. However, a key disadvantage of hydrogen and other PtX products are efficiency losses. For example, the conversion efficiency of the production of hydrogen by electrolysis is estimated to be around 61 % today and 70 % in the future (Oeko-Institut, 2019), also depending on the electrolyser technology used. For PtX products, the conversion losses are even higher. Nevertheless, there are some examples in Germany that are difficult to electrify and have therefore chosen hydrogen as a decarbonisation pathway. Most of the hydrogen produced in Germany today is based on natural gas and is used in the chemical sector and in refineries (DIHK, 2020).

In general, energy-intensive industry is considered an important driver of hydrogen demand in Germany. For example, steel producers can use hydrogen by switching from conventional steel production, which is largely based on coal/coke, to innovative direct reduction technology. Green hydrogen would enable significant CO_2 savings in steel production

In the mobility sector, direct electrification is the main option realised for passenger cars. However, for other sectors such as heavy-duty transport, mobile machinery, shipping and aviation, hydrogen or PtX products are considered more suitable or even without alternatives (National Hydrogen Council, 2021). In the German city of Wuppertal, for example, public buses are powered by hydrogen and fuel cells, partly because of the (mountainous) topography. In addition to Wuppertal, the city of Duisburg also operates a refuse collection vehicle with hydrogen fuel cells. Currently, these and other hydrogen applications do not seem to be economically viable without additional funding.

Hydrogen can also be added to the natural gas grid to a limited extent, in particular to meet heat requirements. There are no blending limits for further processing into methane. However, with regard to the use of hydrogen or synthetic methane blended with natural gas, alternatives must also be considered that are associated with low efficiency losses. The conversion of hydrogen back into electricity in converted gas-fired power plants is also currently being discussed and tested.

Outlook

For the year 2030, the scenarios anticipate a hydrogen demand in Germany of between 18 and 66 TWh; for the year 2045, the demand is expected to rise to between 237 and almost 500 TWh. Even though the new government coalition has raised the expansion targets for electrolysers, there will be a considerable need for imports of (green) hydrogen. Even though there are several barriers associated with green hydrogen, production costs are among the key obstacles (Tholen et al., 2021). Before the natural gas crisis resulting from the Russian invasion of Ukraine, experts assumed that grey hydrogen would remain a cheap option. It will be crucial to improve price development and remove other barriers to hydrogen production and use.

Aspects in the Nexus

Municipal utilities and municipal water management companies are testing in various pilot projects under which technical conditions hydrogen can be produced and in which different fields of application it can be used (Stock, 2022). The combustion of hydrogen produces water (and heat). The literature on recycling water for hydrogen production is limited. If hydrogen production and use do not take place in the same place, a challenge arises for this recycling.

3.2 Hydrogen in German water and wastewater supply

FACTSHEET 3:

Structures, operations and processes in the wastewater sector

Current situation

In Germany, wastewater treatment is largely a public task performed by the municipalities. There are 7,000 municipal wastewater companies and thus a small-scale organisational structure. Sewage treatment plants consume 20 % of the electricity demand in the municipal sector and thus significantly more than other municipal facilities such as schools, hospitals or administrative buildings. This 20 % share amounts to a total of about 4,400 GWh of electricity per year in Germany. In view of rising energy prices and the great need for action in the area of climate and environmental protection, the role of sewage treatment plants is increasingly being discussed in this context. The question of the extent to which not only the technical but also the economic potential exists for the use of innovative technologies at wastewater treatment plants depends, among other things, on the size of the respective plant.

Sewage treatment plants are divided into five size classes, ranging from under 1,000 population equivalents (size class 1) to over 100,000 population equivalents (size class 5). About one third of the operating costs of a wastewater treatment plant consist of energy costs. One way to reduce these is to ferment the sewage sludge produced in the sewage treatment plant and convert the resulting digester gas into electricity in a combined heat and power (CHP) plant on site. The gas used is classified as CO_2-neutral and helps to cover not only the electricity but also the heating needs of the sewage treatment plant.

Another savings opportunity concerns the operation of the aeration basins, which account for about 50 % of electricity costs depending on the size of the treatment plant – in some cases even up to 80 %. Air is supplied to the aeration basins, which ensures an increased oxygen supply for the microorganisms in the basin. The installation of efficient, well-dimensioned turbo blowers pays for itself within a few years and is common practice. Furthermore, the use of pure oxygen can reduce or completely compensate for the need of compressed air.

Emissions can also be avoided with solar thermal sewage sludge drying. The sewage treatment plant in Bottrop is one of the largest in Europe. Sewage sludge with a volume of 4 million population equivalents is treated at the site. Before the conversion, the sewage sludge was enriched with hard coal and lignite to ensure the necessary calorific value for self-sufficient incineration. With the construction of the world's largest solar-thermal sewage sludge drying plant, it is now possible to do without hard coal and lignite. This saves around 70,000 tonnes of CO_2 per year. Electric turning robots ensure constant circulation of the sewage sludge. If solar radiation is not sufficient, heat is supplied from the plant itself or from a combined heat and power plant.

Outlook

Due to demographic change, the German population will decrease from currently about 83.7 million inhabitants to 67 to 73 million inhabitants in 2060. This decline will lead to lower wastewater volumes. Expected longer dry periods will additionally lead to temporarily low discharges. Deposits in the sewage system can lead to corrosion, odour formation and an increased spread of vermin. Adjustments are necessary. This also applies to the increasing heavy rainfall events, which require e.g. the construction of temporary storage tanks, but also the unsealing of areas. Finally, in view of demographic change, increasing consumption of medicines is to be expected in the coming decades, which will increase the demands on wastewater treatment.

Aspects in the Nexus

The decentralised structures of the wastewater sector form a prerequisite for the decentralised hydrogen economy. Oxygen as a by-product of electrolysis can be used for biological purification or ozonation. At sites with sewage sludge digestion and CHP use, methanol production offers advantages. Methanol can be produced with hydrogen from electrolysis and captured CO_2 from the CHP exhaust gases, thus combining different technologies in a synergetic way. The methanol can be used in the wastewater treatment plant as an additive for denitrification in the activated sludge stage

Alternative uses are in the chemical industry or as a fuel.

FACTSHEET 4:

Hydrogen technologies in German water and wastewater supply

Current situation

Sewage treatment plants are seen as a possibility for decentralised hydrogen production in Germany. Sewage treatment plants can use oxygen, which is a by-product of electrolysis, for wastewater treatment, either through pure oxygen in the aeration tank or through ozone to remove persistent trace substances. In addition, the process heat from the electrolysers can contribute to digester gas production. The hydrogen itself can be used either for on-site electricity generation, for blending into the natural gas grid or for mobility purposes.

A few hydrogen projects, mostly in the research and development stage, have been realised at wastewater treatment plants. Already in 2002 / 03, a PEMEL was installed at the Barth wastewater treatment plant together with a PV system to operate the electrolyser. While the hydrogen was used in a fuel cell bus, the oxygen was used in the sewage treatment plant for water treatment. The increase in customers, including two campsites, increased the wastewater load, which required intervention. Such load peaks were managed by feeding in additional oxygen from the PEMEL (Jentsch & Büttner, 2019). In the LocalHy project, a small test sewage treatment plant was set up together with a PEMEL on the site of an operating sewage treatment plant in Sonneberg. Here, too, the focus was on the use of oxygen for wastewater treatment in the biological treatment stage, which has a very high electricity consumption (~55 %). Due to low costs for conventional atmospheric oxygen, one conclusion was that electrolysis oxygen could not substantially reduce the costs for green hydrogen at the time of the project. Under certain conditions, pure oxygen can be an interesting option for wastewater treatment plants.

In the city of Wuppertal, an electrolyser was installed in a waste incineration plant. While the hydrogen supplies part of the city's bus fleet, the oxygen remains unused. Discussions were initiated between the operator of the waste incineration plant and the local wastewater disposal company on how the oxygen from the electrolyser could be used for wastewater treatment. An oxygen pipeline between the two sites faces financial obstacles.

The Wupperverband, an operator of sewage treatment plants in the Bergisches Land region, investigated the role of hydrogen as a flexibility option and electrolysis oxygen for ozonation in research projects. For ozonation, the pure oxygen must be dried and residual hydrogen removed.

High-purity hydrogen for mobile and stationary fuel cells was realised in a test plant at the Emscher-Genossenschaft sewage treatment plant in Dinslaken. Sewage gas was processed here. In another project, (hydrogen-based) methanol was produced in Dinslaken. While biogas is often used in cogeneration in German sewage treatment plants to provide both electricity and heat for relevant processes, the researchers converted the biogas from the sewage treatment plant through methanol synthesis. In particular, they assumed that it may make economic sense to produce a light energy source that can be stored and transported during times when there is a surplus of electricity in the grid and a low demand for heat, especially in summer (Klein, 2022).

The researchers of the Sludge2P project have set themselves the goal of developing a novel process concept to recover phosphate and in which a product gas and a usable fertiliser are produced. In the process, hydrogen is to be separated from the product gas. The remaining residual gas is used to heat the smelting reactor. The German company GRAFORCE can offer two technologies for hydrogen production at the sewage treatment plant to produce hydrogen from the sewage sludge and from the biogas (Opitz, 2022). Stadtwerke Aschaffenburg has so far used grey hydrogen for denitrification of near-surface groundwater. Nitrate is transported through the soil into the water by (intensive) agriculture. The hydrogen is used to treat the drinking water. In the future, green hydrogen will be used for this purpose (Gerlach, 2022).

Outlook

Hydrogen production by electrolysis in wastewater treatment plants is currently not considered an economic case. Thus, it is assumed that the costs for hydrogen production in wastewater treatment plants are over 7 EUR/kgH_2

The use of oxygen in wastewater treatment can reduce hydrogen production costs, but political support seems necessary. No reliable data are available for the costs of hydrogen production from sewage sludge (by pyrolysis or gasification). Local or decentralised hydrogen production is hardly considered in the policy framework of the German government.

Aspects in the Nexus

In summary, the water and wastewater industries provide various resources to produce hydrogen. In addition to fresh water and desalinated seawater, these include treated wastewater, sewage sludge, centrate water and biogas. There are also potential uses, although this depends on the hydrogen production processes used and the associated (desirable) by-products. Sewage treatment plants can theoretically make good use of all products resulting from electrolysis, although the economic viability is not yet given. Appropriate price signals from the electricity system can make the use of electrolysers (or other processes) more attractive as a flexibility option.

3.3 General conditions in Germany

FACTSHEET 5:

Framework conditions for hydrogen

Current situation

Hydrogen plays a key role in the German government's plans for the successful implementation of the energy transition and the achievement of climate protection goals. The focus here is on green hydrogen. The goal is to use this green hydrogen to significantly reduce CO_2 emissions, especially in industry and transport. In addition to the climate policy aspects, green hydrogen technologies are seen as having great potential in terms of jobs and new markets. The goal for Germany is therefore to expand or maintain its global pioneering role in hydrogen technology. Already today, about 55 TWh to 60 TWh of hydrogen are produced and consumed in Germany, most of which is grey hydrogen from natural gas and only about 5 % of which is green hydrogen.

As a first concrete step, the Federal Government published its National Hydrogen Strategy in 2020. It defines the steps that are necessary to help achieve the climate targets, create new value chains for the German economy and further expand international energy policy cooperation.

Outlook

The EU plans to significantly reduce its dependence on imports from Russia. This is also to be achieved through the increased use of hydrogen within the framework of the "Repower EU" (Kantz, 2022). Germany must achieve ambitious climate protection targets by 2030, which cannot be achieved without an ambitious expansion of the hydrogen economy. According to the Hydrogen Council appointed by the German government (as an independent, non-partisan advisory body), some key energy policy prerequisites are indispensable for a functioning hydrogen economy. These include, for example, 1) the more ambitious expansion of renewable energies in Germany and Europe, 2) the industrialisation and establishment of an efficient electrolyser industry, including the supplier landscape and the reduction of the costs of hydrogen, 3) the reform of the tax, levy and apportionment system, 4) the expansion of the infrastructure or 5) technical rules and regulations harmonised at European level.

The Federal Government is providing extensive funding for the implementation of the national hydrogen strategy. As part of the Economic Stimulus Package 2020, the Federal Government has earmarked nine billion euros (seven billion euros for the national market, two billion euros for international partnerships) for the implementation of the strategy. For example, the Federal Ministry of Economics and Climate Protection is providing 900 million euros for the "H_2Global" programme. With this programme, the market for green hydrogen is to be advanced via so-called double auction procedures. To match supply and demand, an intermediary company concludes long-term purchase contracts on the supply side and short-term sales contracts on the demand side. Taking sustainability criteria into account, the lowest bid price or the highest sales price is awarded the contract.

The national hydrogen strategy targets a domestic production of green hydrogen of 5 GW for the year 2030, which has been increased by another 5 GW by the new government coalition in Germany. As this production will be far from sufficient to meet demand, much of the hydrogen will have to be imported. The German Hydrogen Council therefore also calls for a significantly higher electrolysis capacity to be aimed for, secured by the expansion of additional renewable energies.

To ensure the implementation of the strategy, numerous existing laws, regulations, programmes and standards must be adapted or reformulated. In particular, there is a great need to develop a uniform or European harmonised system of certified and standardised guarantees of origin for climate-neutral hydrogen.

Aspects in the Nexus

So far, no challenges to hydrogen production in Germany are known to exist with regard to the availability of hydrogen carriers from water and wastewater management, although this may indicate a research gap. Water use by companies has recently been the focus of local protests (e.g. Lüneburg, Grünheide), possibly suggesting resistance to a future electrolysis economy that will eventually require water. Extreme weather will have an impact on water availability in Germany and seasonally exacerbate conditions. The use of resources from wastewater management can partially resolve this conflict. In the context of increasing droughts and limited fresh water availability, the use of wastewater resources can help to stabilise hydrogen production during hot spells. However, since Germany will mainly import hydrogen, conflicts are more likely to occur abroad. Electrolysis hydrogen is currently the political and public focus, which means that other processes that can also enable decentralised hydrogen production receive less attention.

FACTSHEET 6:

Framework conditions in the water and wastewater sector

Current situation

Since the drought events in the summers of 2018-2020 and the fatal floods in the summer of 2021, the resource "water" in Germany has become the focus of greater public and political attention. The German population is used to water being available at all times, in any quantity and in the best quality. On average, each person in Germany consumed around 123 litres of drinking water per day in 2016. However, climate change is putting increasing pressure on water as a resource. Dry summers cause groundwater levels to drop and soil moisture to decrease; water reservoirs and wastewater systems have to adapt to the changed conditions. In addition, especially in regions with intensive agriculture, nitrate is becoming a problem for groundwater. However, drinking water is still available in high quality; water quality is checked very frequently – often daily. It is also much cheaper than bottled water: A litre of drinking water from the tap costs less than one euro cent.

In Germany, water supply and wastewater disposal are core tasks of public services of general interest and are the responsibility of the municipalities. Their democratically legitimised bodies make the strategic decisions on organisational forms, participations and cooperations.

The European Water Framework Directive is the central regulatory framework for the protection, management and use of waters in Europe and sets far-reaching goals for the biological-ecological, physical-chemical and quantitative status of groundwater, surface waters and coastal waters. This EU directive has been transposed into German law. However, although the pollution of water bodies by anthropogenic substances has decreased in Germany in recent decades, surface waters in particular do not meet the standards due to ubiquitous substances such as mercury or brominated diphenyl ethers as well as fertilisers and pesticides. In addition to the European Water Framework Directive, there is an extensive and often complex set of regulations for substances. These include, for example, registration and authorisation requirements for chemicals, pesticides and pharmaceuticals, emissions for wastewater discharges and quality standards for water bodies. For the protection and sustainable use of water as a resource, there is currently a draft of the national water strategy coordinated within the Federal Government.

Outlook

Demographic change and climate change are expected to become major challenges for the German water sector in the coming decades. In general, sufficient water resources are available, but the industry expects longer periods of drought (exacerbating the conflict between irrigation and drinking water) and more frequent local heavy rainfall due to climate change. Demographic change is also expected to have a regional impact: In some regions, water demand and wastewater production will decrease, while demand will increase, especially in urban areas.

As part of the European Green Deal, the European Commission published an "Action Plan to tackle pollution of air, water and soil" in 2021. The Action Plan integrates all relevant EU policies in the field of pollution prevention and control, with a particular focus on the use of digital solutions. It also provides for a review of relevant EU legislation to identify where gaps remain and where better implementation is needed to meet these legal obligations.

Another upcoming issue for the water sector will be the maintenance and renewal of the existing infrastructure. The continuous maintenance of the infrastructure and the associated facilities is one of the tasks of the water utilities. In this way, they ensure the operation and performance of the facilities. In the coming years, considerable investments in the fundamental renewal and expansion of the infrastructure and facilities will be necessary in order to secure them in the long term, to adapt them to new requirements and to maintain the asset value for the municipalities.

Aspects in the Nexus

In Germany, water consumption has been significantly reduced in recent years. If this trend can be continued, there is potential for an electrolysis-based hydrogen economy that does not lead to conflicts with other water users. The National Water Strategy addresses "innovative energy carriers such as hydrogen"; their production should not interfere with other water uses. Currently under discussion is the question of whether a fourth purification stage should be made legally obligatory for sewage treatment plants. Since the ozonation of wastewater is a possibility here and ozone can be produced via electrolysis oxygen, such a regulation can become a driver for a decentralised hydrogen economy at sewage treatment plants, provided that the hydrogen can be used appropriately. Due to future hydrogen imports to Germany, the water and wastewater legal framework conditions in the partner countries must be analysed.

3.4 Water-hydrogen nexus

The water-hydrogen nexus understood here is characterised by the focus on the water and wastewater sector in terms of hydrogen production. This reveals the different hydrogen carriers from the sector.[2] These different carriers require different processes to produce the target product (hydrogen), which can eventually be fed to context-specific applications (e.g. heavy duty transport, public transport). The processes also require some form of energy (e.g. electricity). In addition to the target product, there are also other by-products (e.g. oxygen, waste heat) that can ideally be put to good use (e.g. in ozonation). The complete utilisation of all products can minimise costs or achieve additional benefits. The following figure provides an overview of the water-hydrogen nexus.

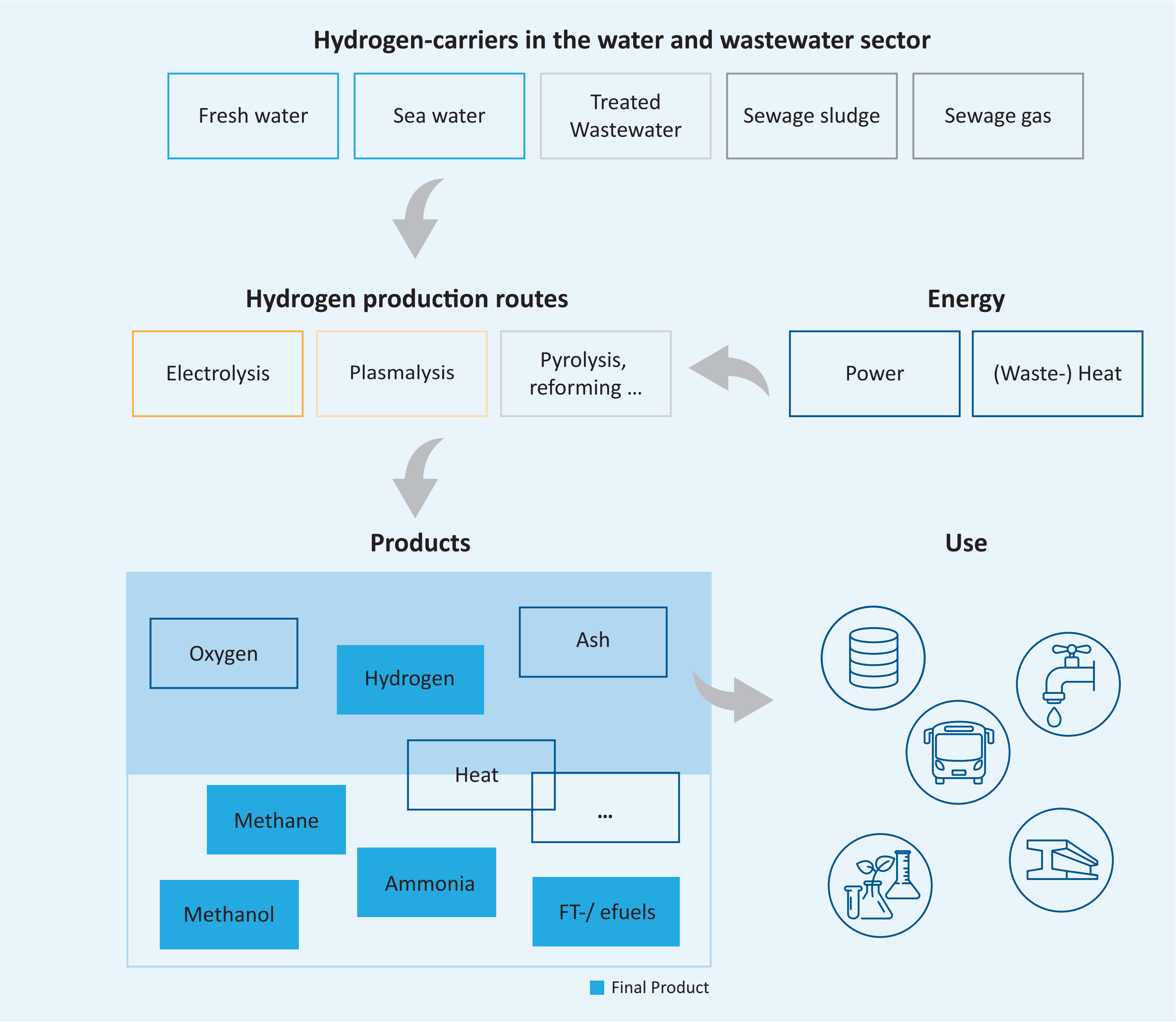

Figure 4
The water-hydrogen nexus as a conceptual basis in the project (own representation)

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[2] It is true that natural gas-based hydrogen processes such as steam reforming also require water. However, since natural gas is a non-renewable raw material, the schematic-conceptual embedding was dispensed with, also in order to focus attention during the workshops on long-term sustainable forms of hydrogen production.

4 | Prospects for a Jordanian hydrogen economy

For the purpose of identifying opportunities and challenges for a decentralised hydrogen economy in Jordan, fact sheets were developed based on literature research and the contents of the workshops.

4.1 Opportunities and challenges for hydrogen in Jordan

FACTSHEET 7:

Investment conditions in Jordan

Current situation

In the view of the German-Arab Chamber of Industry and Commerce (AHK, 2020) Jordan is a good investment destination as King Abdullah II is keen to open up the Jordanian economy and create a suitable environment for foreign investors. Several trade agreements with the European Union already allow Jordan smooth access to the European market. According to the Doing Business Index, Jordan ranks 75th out of 190 countries in terms of investment climate. By comparison, Germany is in 22nd place.

According to the ranking, Jordan performs worse in the areas of business start-ups and building permits, while conditions are better in the areas of taxes, electricity and availability of credit.

As part of its international energy policy, Germany supports Jordan in developing the renewable energy sector. In this context, the "Energy Dialogue" was launched, the "Energy Export Initiative of the Federal Ministry for Economic Affairs and Energy" was implemented and export credit guarantees, such as the "Special Initiative Renewable Energies", were established. In addition, the Kreditanstalt für Wiederaufbau (KfW) supports solar and wind energy projects, with the PV project in the Za'atari refugee camp being the best known. France and Japan are also involved in Jordanian renewable energy projects: for example, the French Development Agency (AFD) has launched the SUNREF (Sustainable Use of Natural Resources and Energy Finance) initiative, which aims to implement small-scale renewable energy projects in homes and businesses, while the Japanese Bank for International Cooperation (JBIC) offers loans for large-scale projects such as the Shams Ma'an project (ibid.). The European Union has also launched several programmes and promotes the development of renewable energies in Jordan on the basis of the "Association Agreement between the European Union and the Hashemite Kingdom of Jordan". Between 2017 and 2020, a total of 410.10 million euros was available for Jordan's social and economic development, with renewable energy as one of the main pillars within these funds. The European Bank for Reconstruction and Development (EBRD) finances up to 35 % of the total project cost of renewable energy facilities and has so far provided 1.5 billion euros to 50 projects. For example, the EBRD was involved in financing the large Al Rajef wind farm and the Shobal wind energy project. Other international organisations also provide capital for energy efficiency and renewable energy projects in Jordan. For example, the Global Energy Efficiency and Renewable Energy Fund (GEEREF) or the OPEC Fund for International Development (OFID) have been involved in some solar and wind power projects. The best-known project supported by OFID is the 117 MW Tafila wind power project (AHK, 2020).

According to IRENA (IRENA, n.d.) there have been numerous international renewable energy finance flows to Jordan over the past decades. The financing flows include different types of financing, such as equity investments, green bonds, investment funds, grants and loans from international institutions and lenders for renewable energy technologies.

Outlook

Jordan has a stable and strong banking sector, which facilitates access to capital and improves the investment climate. The renewable energy tenders regularly published by the Ministry of Energy and Mineral Resources attract private companies to implement projects (AHK, 2020). As far as green hydrogen and its value chain are concerned, Jordan still has a long way to go. Concrete public and private financing mechanisms are needed to fund projects. Knowledge and expertise on green hydrogen need to be built among financial and banking institutions to facilitate access to capital. Here, the experience in raising finance for renewable energy from both local banks and international financial institutions and the stable investment climate should be helpful, especially at the beginning of the development of green hydrogen (Wuppertal Institute et al., 2022).

The level of education of young people can generally be described as good – an important prerequisite for operating and maintaining investments in capital-intensive plants. However, specific capacities for the production and handling of hydrogen must be created. To this end, the German-Jordanian University and the University of Applied Sciences Würzburg-Schweinfurt are planning to transfer a curriculum for hydrogen technology. This cooperation also serves the purpose of training corresponding specialists beyond the Jordanian borders (Al-Halhouli, 2022; Al-Salaymeh, 2022).

Aspects in the Nexus

Due to the relatively good investment climate, the commitment of different donor countries and some experience in climate-friendly projects, Jordan fulfils important conditions for the implementation of capital-intensive hydrogen projects. However, the above challenges need to be addressed and aspects need to be thought together in the nexus. For electrolysis in particular, water as a resource is an important input factor for the long-term operation of the plant.

FACTSHEET 8:

Energy supply and demand in Jordan

Current situation

Jordan does not have abundant oil and gas resources like other countries in the region, apart from oil shale deposits that have only recently been developed. Jordan therefore imports around 90 % of its energy to meet rising national demand (IRENA, 2021). In 2018, a significant amount of 10 % of the public budget was spent on securing energy supplies through imports (Abu-Rumman et al., 2020). Against this backdrop, and given the disruption of Iraqi oil supply in 2003, the Egyptian natural gas crisis in 2011, as well as the huge influx of refugees and the resulting increase in energy demand, Jordan has focused on developing renewable energy as a domestic energy source. The energy transition towards renewables is thus primarily driven by the need to ensure energy security and reduce dependence on imports. And Jordan has made significant progress in the use of renewable energy over the last decade. The share of renewables in electricity generation was 20 % in 2020 and has the potential to increase further in the future.

Jordan is characterised by a steadily increasing demand for energy due to industrial development, urbanisation and demographic change. In 2019, Jordan's total final energy consumption was 6,465 ktoe, with the mobility sector accounting for the largest share of consumption, followed by the residential sector, industry and the commercial and public services sector (IEA, 2022a). Natural gas-fired power plants dominate electricity generation in Jordan. Jordan has a liquefied natural gas (LNG) terminal in Aqaba, which was commissioned in 2015 and will be expanded to diversify natural gas resources. Jordan has also been importing natural gas from Israel since 2020. The National Electric Power Company (NEPCO) counted a total installed capacity of 5,424 MW in 2020. The installed renewable energy capacity connected to the grid is 2,280.5 MW, of which more than 35 % is connected under the net metering and wheeling system. By 2030, the installed renewable energy capacity is estimated to reach 3,300 MW. The overall national energy sector strategy for 2020-2030 projects that 31 % of the total electricity generation and 14 % of the total energy mix will come from renewable energy sources by 2030 (IRENA, 2021).

As in most countries in the MENA region, the energy sector is characterised by a high degree of state involvement and regulation. However, unlike other countries, Jordan started unbundling the power sector as early as 1996. In 2002, Jordan liberalised its power generation and allowed private investment through IPPs (Independent Power Producers). However, NEPCO continues to act as the sole buyer of electricity and continues to own and operate the transmission grid. NEPCO is also responsible for negotiating power purchase agreements with the IPPs. At the distribution level, the three distribution companies, JEPCO (Jordan Electric Power Company), EDCO (Electricity Distribution Company) and IDECO (Irbid District Electricity Company) are responsible (Franceschini, 2019).

A number of initiatives and policies have been introduced to promote the use of renewable energy. For example, priority access and feed-in is guaranteed for renewable energy, and the establishment of a one-stop shop at the Energy and Minerals Regulatory Commission (EMRC) helps to encourage private sector investment in renewable energy by simplifying many procedures (RCREEE, 2013). In addition, targeted government financial incentives, such as feed-in tariffs, tax and duty exemptions, have supported the uptake of renewables (IRENA, 2018). Overall, the policy and regulatory framework for renewable energy in Jordan is considered one of the most advanced in the MENA region. Renewable energy projects are generally implemented in three ways: IPPs can participate in tenders for projects under the Build-Own-Operate (BOO) model and sign long-term power purchase agreements (PPAs) with NEPCO; government-owned projects offered as engineering, procurement and construction (EPC) contracts; or self-consumption projects (wheeling and net metering). Large photovoltaic power plants are mainly located in the southern Ma'an region and have a capacity between 10 and 50 MW. There are also numerous wind farms, such as the Tafila wind power plant with a capacity of 117 MW (Abu-Rumman et al., 2020). So far, however, small-scale wheeling and net-metering projects have predominated, making a significant contribution to the share of renewable energy in the electricity mix. However, a bottleneck for the further expansion of renewable energy in Jordan is the technical limitations of the electricity grid. To prevent grid instability, the Ministry of Energy and Mineral Resources (MEMR) has set a cap on grid-connected renewable energy projects above 1 MW for 2019, which will apply until grid stability analyses are conducted (Franceschini, 2019; IRENA, 2021).

Outlook

In addition to the general challenges in the energy sector, such as the high dependence on imported fossil fuels and the associated costs, as well as securing the energy supply in the face of increasing demand, system integration and grid stabilisation are among the most important challenges for the further expansion of renewable energies in Jordan (Aldohni, 2022). In addition, Jordan currently has a surplus of electricity generation, which raises further questions about storage, grid expansion and interconnection that are becoming increasingly urgent to address.

To meet these challenges in the face of the increasing share of intermittent solar and wind energy, the development of storage options, research into sector coupling and other flexibility options are being discussed. For example, a large-scale lithium-ion battery project with an energy storage capacity of 12 MWh is planned, coupled to a 23 MW PV farm to allow flexible use of the electrical storage. Another storage technology that is expected to play an important role is pumped hydroelectric energy storage (PHES). In this context, several feasibility studies are being carried out to assess the viability of PHES projects, with Al-Mujib considered to have the greatest potential with 200 MW capacity (IRENA, 2021). In addition, electric mobility is also being promoted in Jordan, here the country is one of the pioneers in the MENA region in terms of deployment (Shalalfeh et al., 2021).

Other options that should be explored are load management measures, i.e. demand side management, as well as the use of synergies through digitalisation, storage and mobility.

Aspects in the Nexus

Germany works closely with Jordan on energy issues and founded the German-Jordanian Energy Partnership in 2020, which provides a platform for intensive exchange on energy-related topics. The stable political situation and the excellent potential for renewable energies form a good starting position for hydrogen production in Jordan. In this context, it must be considered what role hydrogen is to play for the Jordanian energy system, as it also depends on whether electrolysers are grid-connected or become stand-alone solutions.

FACTSHEET 9:

Water as a resource in Jordan

Current situation

Jordan is considered one of the most water-scarce countries in the world, and the country's water supply is considered very vulnerable. Groundwater is considered the most important source of water supply in Jordan. Nearly two-thirds of its water comes from aquifers, from which water is pumped at an unsustainable rate (Whitman, 2019). About 51 % of water consumption is for agriculture, 45 % for households and 4% for industry. Annual individual water consumption is 100 m³ per capita, compared to a global average of 5,700 m³ (International Trade Administration, 2022; Ritchie & Roser, 2017). Available renewable water resources per capita are steadily decreasing due to population growth and the influx of refugees. Thefts and leaks in municipal water networks further exacerbate the water situation (Whitman, 2019); this so-called non-revenue water amounts to 50 % of water production. Electricity costs account for 57 % of the water sector's operating costs. In addition, the impacts of climate change are likely to increase the risk of water scarcity as rainfall patterns change and rising temperatures accelerate evaporation. As water demand already exceeds supply from aquifers, surface waters and lakes, Jordan is seeking to diversify water supply sources, e.g. through desalination.

The Jordanian government supports the approach of performance-based operation of wastewater treatment plants, which are mainly operated by the private sector under a build-operate-transfer (BOT) contract. The recent upgrading of 33 existing treatment plants has contributed to smoother operation and management, alleviating the tense water situation. For example, the amount of treated water used for agriculture and industry has been increased from 110 to over 144 million m³ per year (Wuppertal Institute et al., 2022). This upgrade also enabled a significant increase in the amount of water that can be used for municipal water use (ibid.).

Outlook

To counteract the water shortage, several desalination and water treatment projects using different technologies, such as reverse osmosis, have been implemented or are in the planning stage. In addition, the Aqaba-Amman water desalination and transfer project is a major project planned to improve the water situation (Roscoe, 2022). The project is expected to produce about 300 million m³ of desalinated water annually, of which 250 million m³ will reach Amman and other regions. The remaining 50 million m³ is still to be decided or can be used by the operator in a market economy (Marar, 2022; Tetra Tech International Development, 2022).

Aspects in the Nexus

Against the background of the currently already very strained water situation in Jordan, water will be one of the biggest challenges for establishing a green hydrogen value chain in the country. Without available groundwater or surface water resources, the production of green hydrogen must be accompanied by the large-scale implementation of seawater desalination plants. The development of desalination plants for green hydrogen production must take into account the availability of land and land use along the Red Sea coast. While Jordan can be considered a promising case for green hydrogen production as it has long experience with public-private partnerships (PPP), social acceptance of water use for hydrogen production could be a challenge given the water scarcity in Jordan (Wuppertal Institute et al., 2022). Should the operator of the planned desalination plant market the 50 million m³, which it has at its free disposal annually, to hydrogen producers, large-scale hydrogen production through electrolysis is possible.

FACTSHEET 10:

Prospects for Jordanian hydrogen production

Current situation

So far, green hydrogen is not part of Jordan's 2020 – 2030 energy strategy, but according to Jordan's Ministry of Energy and Mineral Resources, the country is currently working on a national roadmap for green hydrogen and derivatives (The Jordan Times, 2021). In collaboration with the Jordanian-German Energy Partnership and Dutch partners, several studies and consultations are currently underway to support the design and development of the national roadmap for green hydrogen (Marar 2022). The draft roadmap, to be finalised in 2022, will be validated by governmental, legislative and public bodies in Jordan.

The first Memorandum of Understanding focusing on green hydrogen was signed by the Jordanian government and the Australian company "Fortescue" during COP26 in Glasgow (Atchison, 2021). Under this MoU, the partners agreed to conduct feasibility studies for a 5 GW electrolyser project in the south of the country, to be powered by off-grid wind and solar energy. Depending on the outcome of the studies, an investment agreement will be negotiated for the production of green hydrogen and/or green ammonia in Jordan and its export to Australia. The preliminary studies will cover an area of 450 km² for potential solar production, while 1,000 km² will be reserved for potential wind energy production and 1.5 km² within an industrial zone will be set aside for potential downstream production facilities (Ivanova, 2021).

Outlook

Jordan has the potential to become a major regional and international player in hydrogen. The country has large solar and wind energy resources and masters gas and ammonia infrastructure, such as gas pipelines, ammonia storage and energy infrastructure in the seaport of Aqaba. This is a good starting point for the development of a green hydrogen and synthetic fuels industry (Wuppertal Institute et al., 2022). In terms of industrial development, Jordan has a chemical industry based on potassium and phosphate, which is a strong economic pillar for exports. Jordan could use the existing chemical industry structures to build a comprehensive value chain for green hydrogen. In addition, Jordan has experience with the storage of natural gas in salt caverns near Amman and Aqaba, which can also be used for green hydrogen storage.

The World Bank is currently supporting a study on e-mobility in Jordan (Marar 2022). Possibilities for hydrogen use in (heavy duty) transport should be discussed (in the future).

Aspects in the Nexus

The main challenge for the development of green hydrogen production in Jordan will be the supply of water resources, as this is likely to lead to competition with other sectors such as agriculture, industry or housing. In addition, land use competition between urbanisation, tourism and industrial activities could become an issue, especially on the narrow coastal strip around Aqaba. Overall, the transition to a hydrogen economy requires the strengthening and expansion of national infrastructure and the development of various support mechanisms and policies. Equally important is strong private sector participation with foreign and national direct investment. Therefore, cooperation with international partners on green hydrogen projects will be necessary to promote a hydrogen economy in Jordan (Wuppertal Institute et al., 2022).

In addition to the potential export of green hydrogen or its derivatives, Jordan also needs to examine where local demand could develop in the future. To this end, the potential applications of green hydrogen and its derivatives need to be explored, especially in sectors that cannot be electrified or are difficult to electrify, such as certain industrial applications or air and maritime transport. In order to build a green hydrogen industry in Jordan, innovation and research and development (R&D) platforms need to be created that bring together private sector actors, existing R&D centres, universities, public bodies, and national and international institutions. The regional dynamics related to green hydrogen in the Middle East also offer significant potential that Jordan could exploit (Wuppertal Institute et al., 2022).

An important starting point for further discussion of water-related energy issues in Jordan is the Water-Energy Nexus Working Group. This working group is a kind of coordination mechanism to identify issues and projects that are relevant to both sectors. Hydrogen could be addressed here.

Textbox 1

Coordination mechanism on the Water-Energy Nexus in Jordan

Supported by GIZ, a water-energy nexus dialogue was initiated in 2019. A steering group was formed from this. Representatives include:

- **Ministry of Energy and Natural Resources,**
- **Ministry of Water and Irrigation,**
- **Ministry of Planning and International Cooperation and**
- **Ministry of Finance.**

In addition to the ministries, other institutions such as NEPCO are part of the steering group, which enables better coordination of projects relevant to the water and energy sector. Appropriate projects are selected within the framework of in-depth analyses by sub-working groups and the involvement of third parties. The development of a pumped storage facility is part of the project portfolio of the coordination mechanism. Hydrogen could also be addressed in this context in the medium term (Qaider & Sadeh, 2022).

4.2 Contributions of a hydrogen economy for Jordan

During the workshop in Amman, participants were asked the following questions in interactive sessions:

1) What positive effects and negative impacts need to be considered for a hydrogen economy?

The evaluation of the recorded feedback can be structured into five or six categories. An overview of the categories with the number of mentions can be found in the following figure.

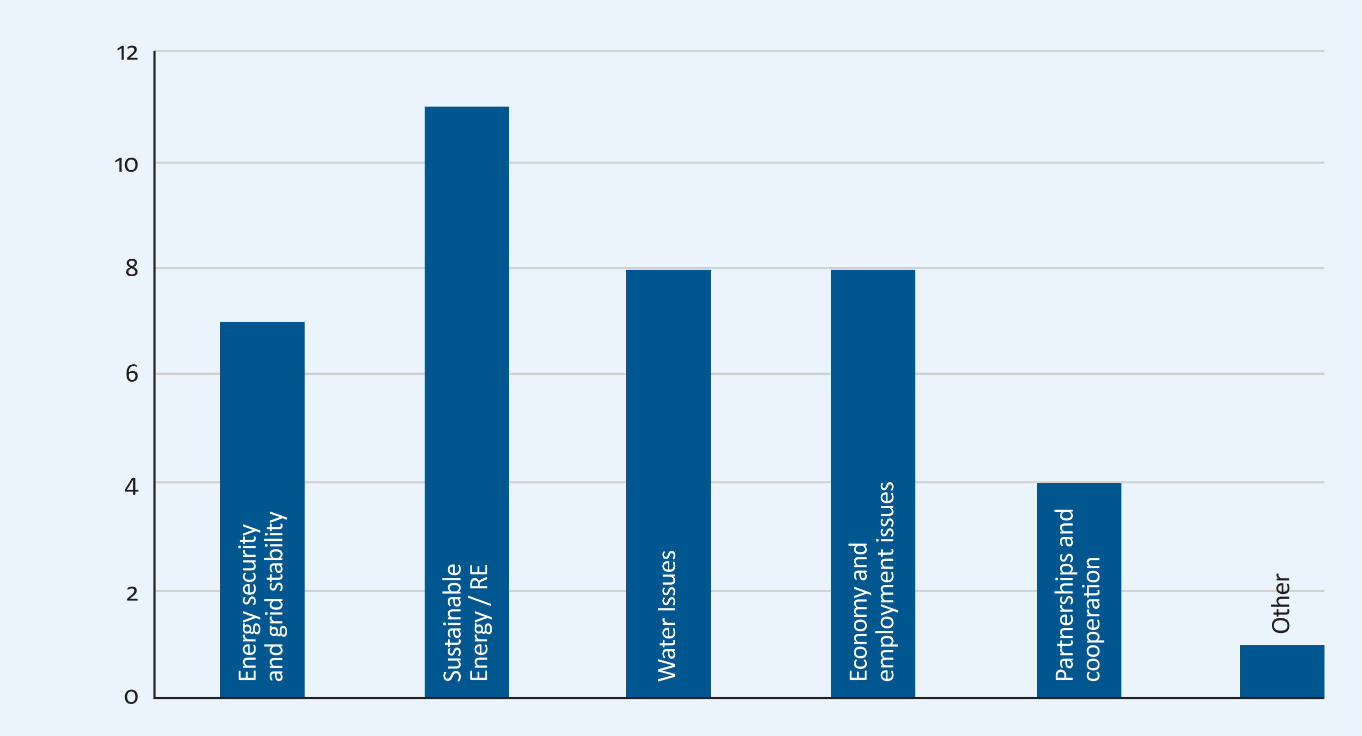

Figure 5
valuation of the first interactive workshop session

The topics "Energy Security and Grid Stability" and "Sustainable Energy / Renewable Energies" have a high degree of overlap and could also be combined in a superordinate category "Energy".

In the category "Energy security and grid stability", the positive role of electrolysers was pointed out, which can stabilise electricity grids in Jordan and at the same time store (surplus) electricity in gaseous form. In addition, hydrogen can act as a driver for the expansion of renewable energies, which can ultimately contribute to energy security (in the sense of energy import independence). It is unclear how the local use of hydrogen can look in Jordan.

The category "Sustainable Energy / Renewable Energies" contains the most ideas. Here, particular reference was made to the expansion of renewable energies, for which hydrogen can be a driver. The hydrogen produced should ultimately make a contribution to CO_2 reduction, whereby the question is whether this contribution should be made in Jordan or abroad. Theoretically, a tension can arise, as Jordan has some industries that require imported ammonia, for example. So why should green ammonia be transported (at great expense) to Europe when it can also be used (at least in part) in Jordan and make a local contribution to defossilising the fertiliser industry? Due to the conventional (natural gas-based) alternatives and their costs, the question of the willingness to pay for green products was also raised elsewhere, a topic that must be considered in a differentiated manner with regard to the various users of ammonia in the different regions of the world and their buyers.

Another important category was the topic of "water". It was particularly important to the participants that a hydrogen economy does not increase conflicts over the distribution of water resources. Further points are the avoidance of negative environmental effects on the maritime ecosystem through seawater desalination plants, which must not be used exclusively for hydrogen production; the management of water in a cycle (which fuel cells (FC) can make possible) and the opportunity to raise awareness among the population for water as a resource through a hydrogen economy. Awareness raising should be part of a water strategy. The use of emerging untreated wastewater for electrolysis was currently commented as "little researched", while treated wastewater is massively used in agriculture in Jordan. In this respect, hydrogen production from treated wastewater would also be in conflict – if the volume of treated wastewater remained constant.

The topic of "economy and employment" forms another important category. A hydrogen economy in Jordan should not exacerbate poverty in the country, but – on the contrary – lead to economic growth, introduce new industries and create long-term employment also in peripheral parts of the country. The question here is how an export-oriented hydrogen economy compares to an alternative that also uses hydrogen locally. Technology transfer was mentioned as an important condition for the above-mentioned economic policy impulses.

This type of cooperation can also be grouped in the next category "partnerships and cooperation". The catchword "win-win situation" was also mentioned more often in the workshop itself. For this purpose, the exchange between partner countries should be promoted and competences should be developed locally.

2) Name three concrete steps or project ideas that are important to realise a hydrogen economy in Jordan.

The answers can be structured into four or five categories. An overview of the categories with the number of mentions can be found in the following figure.

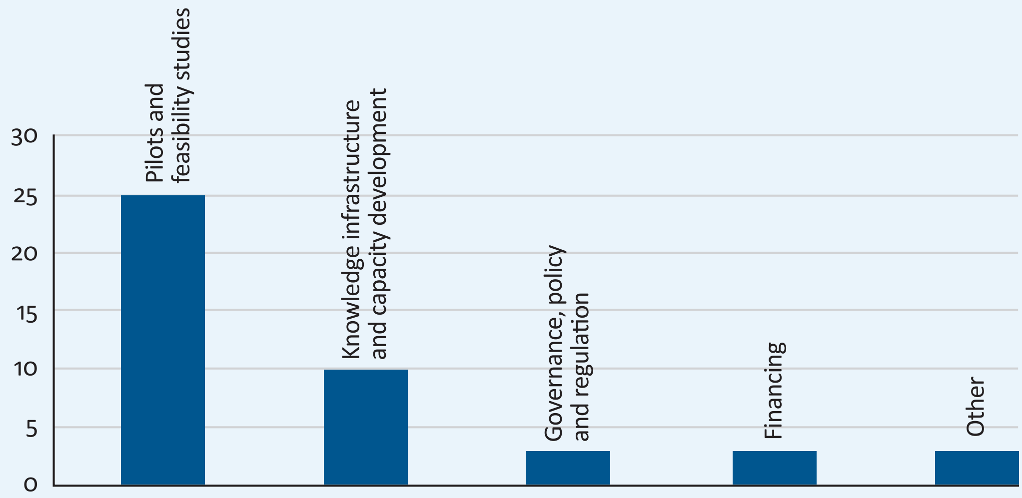

Figure 6
Evaluation of the second interactive workshop session

Perhaps also due to the technical expertise among the participants, "pilot projects and (technical) feasibility studies" in particular were seen as an extremely important step for a hydrogen economy in Jordan. In parts, very specific ideas were named, which also clearly differ in their ambition levels. Small-scale ideas are

- Construction of a floating PV system in combination with an electrolyser, possibly continued by ammonia, methanol or FT synthesis processes (see text box 2),
- the use of all electrolysis products such as hydrogen, oxygen and waste heat,
- Piloting of other processes such as BEST (BioEnergy STorage) developed by HTW Saar (see text box 3),
- Focus on industrial applications in Jordan,
- Implementation of a water management project linked to aspects of a hydrogen economy.

Textbox 2

Floating PV in combination with electrolyser as pilot project

Jordan is considered one of the world's most arid countries in terms of water resources and rainfall. On average, about 1,000 litres of precipitation fall per year. In Germany, it is about 11 times as much[3] (Länderdaten, o. J.). Due to the frequent sunny days (about 310 per year), Jordan also has a very high evaporation rate. Various approaches have already been taken to improve Jordan's water balance. These include the restructuring and rehabilitation of old water networks, awareness-raising and education campaigns for the population and increased reuse of water.

One approach being explored by the Jordanian University of Science and Technology (JUST) is to mitigate evaporation rates using floating photovoltaic (FPV) systems. FPV is an already established technology. In Asia, projects with an installed capacity in the double-digit megawatt range have already been realised. In Germany, the installation of FPV on open-cast lignite lakes is being investigated. Currently, the economically feasible potential in Germany is estimated at at least 2.74 GWp. In a project carried out by JUST, the use of FPV was investigated in terms of PV system efficiency, water quality and evaporation rate. This showed that both the efficiency of the PV plants is increased and the water quality is improved, as well as the evaporation rate is reduced. The efficiency of the PV systems increased by about 8 % compared to free-standing systems, due to the cooling by the water. With regard to water quality, a reduction in algae production was observed, which was partly due to a lower pH value and an increased carbon content. With regard to evaporation, depending on the degree of shading of the water surface, a reduction of up to 54 % was measured compared to an unshaded water surface. The water saved by the reduced evaporation could be used, for example, in the production of hydrogen.

Since FPVs can be installed on any water body, they are an efficient option for simultaneously producing sustainable energy, improving water quality and saving water.

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[3] https://www.laenderdaten.info

Textbox 3

Synthetic natural gas through the BEST process of the HTW-Saar

In the biotechnological process "Bio-Energy Storage", climate-damaging CO_2 is converted by microorganisms with the help of hydrogen and electrical energy into synthetic methane of natural gas quality, which replaces fossil natural gas 1:1. The bacteria are in an aqueous solution inside a simple bioreactor. Temperature (30 – 40° C) and pressure are low, so the effort of BEST is estimated to be low compared to alternative synthesis processes with high operational safety. Since there are no moving parts in the reactors, operation and maintenance of the plant do not pose any significant problem.

Pilot plants have already been implemented at an industrial wastewater treatment plant and at the Trier municipal utility. Despite strong fluctuations in the load of the plants, the CO_2 -containing biogases produced there could be robustly converted to methane of natural gas quality without any pre- or post-treatment. In the future, the required hydrogen can be produced from electrolysis. With regard to the water-hydrogen nexus, a particular advantage of the BEST process is that water is formed as a by-product.

BEST-procedure: $4\ H_2 + CO_2 <=> CH_4 + 2\ H_2O$

This water can in turn be fed into the electrolysis after treatment.

Water electrolysis: $2\ H_2O \rightarrow 2\ H_2 + O_2$

The BEST process combined with water electrolysis makes it possible to reduce the amount of water needed to produce hydrogen.

Synthetic methane can be fed directly into natural gas pipelines without limitations. By substituting fossil natural gas, no additional CO_2 enters the atmosphere. Moreover, domestically produced (synthetic) methane can contribute to energy security. Liquefied into LNG, it can also be transported to Europe (more easily than hydrogen).

The process was developed by the Saarland University of Applied Sciences (HTW). Prof. Dr. Matthias Brunner from HTW Saar presented the BEST process in Jordan as part of the project.

There is agreement that these pilot projects should train human capital for a possible hydrogen economy in Jordan. Although the contribution to the stabilisation of the electricity grid was pointed out the day before, it seems to make sense for the participants to develop demonstration projects as isolated solutions first. A first study on green hydrogen in Jordan has already been published by the RSS on behalf of the Friedrich Ebert Foundation, and another is being prepared on behalf of the GIZ. Further ideas for feasibility studies from the participants are:

- Hydrogen production at the sewage treatment plant,
- Impact of a seawater desalination plant exclusively for hydrogen production.

“Knowledge infrastructure and capacity building" has some overlap with the previous category. Here, platforms, institutions, workshops and trainings are considered important. The exchange between Germany and Jordan was discussed more frequently throughout the workshop, although cooperation between other MENA countries can also be useful, not least because this group of countries faces similar challenges. Both universities and the network formed from the present project were named as important stakeholders.

For some participants, the topic of "governance, policy instruments and regulation" was also in the foreground. Here, the importance of a political agenda and strategy was pointed out, which can also have a signal effect for funding agencies. In this context, the importance of a (non-technical) study on the political framework in Jordan was also mentioned.

In the category "Funding", reference was made to the importance of subsidies.

4.3 Outlook for hydrogen import criteria

Since the topic of a "win-win situation" was raised at various points in the workshops, this should be linked to. For Jordan, a hydrogen economy seems to be advantageous if hydrogen:

- makes a contribution to energy security that is characterised by
- stabilisation of the electricity grid or
- the integration of increasing and accelerated expansion of renewable energies,
- contributes to decarbonisation,
- does not exacerbate existing or new water conflicts, but ideally reduces them,
- further technology requirements (PV, desalination plants) do not have a negative ecological impact,
- is accompanied by a campaign to raise awareness among the population about water as a resource,
- has a positive socio-economic impact (economic growth, employment, innovation), ideally also in decentralised regions of the country, and
- creates capacities on site,
- in Jordan is supported by partner resources.

5 | Summary and outlook

Looking at the situation in Germany in particular shows that the connections between the water and wastewater sector as well as the hydrogen production and use are manifold. Besides the energy sector, the water sector will be the other mainstay of hydrogen producers. But wastewater can also be a resource, especially if a decentralised approach is to be used for hydrogen production.

Potential business models in the hydrogen sector are currently of limited viability and depend on various factors. In addition to operating costs (especially for resource inputs such as electricity), these include the funding landscape and opportunities to use hydrogen sensibly. Furthermore, ideas must be found for the valorisation of those by-products that are generated by the various processes.

Hydrogen can be used in different sectors, although adaptations must first be made. One field of application is the water and wastewater sector itself, e.g. to denitrify drinking water. The derivative methanol can also be used for the denitrification of wastewater or the regeneration of activated carbon. At sewage treatment plants, by-products such as (waste) heat or pure oxygen can in principle also be incorporated for biological purification or ozonation.

Electrolysis is of particular importance in the discussion about green hydrogen. While renewable electricity is the limiting resource in Germany, water scarcity is another challenge in countries like Jordan.

For green hydrogen, which according to the current definition can only be produced via electrolysis, no fresh water can be used in Jordan, as this would increase existing (social) tensions. Great hopes are pinned on the desalination plant in the Red Sea, also to use part of the desalinated water for electrolysis. Treated wastewater is used for agricultural purposes in Jordan. Sewage sludge or sewage gas may be options for hydrogen production.

Since seawater desalination cannot be put into operation before 2028, the question arises as to how the way can be paved in Jordan for a national hydrogen economy by developing appropriate framework conditions and building capacities and structures.

Since both Jordanian and German participants considered the dialogue to be fruitful, it should be intensified and consolidated, whereby the specific challenges must continue to be taken into account. In this context, a cross-stakeholder dialogue – as envisaged by the project – is of particular importance in the future in order to be able to keep track of the complex technical issues such as hydrogen. An important signal from local politics would be to embed hydrogen production in political strategies that are developed across sectors. Preliminary studies on promising pilot measures that address the specific challenges for a hydrogen economy in the country can in turn send important impulses to policymakers.

In addition to an in-depth discussion of hydrogen use, such preliminary studies should also include the discussion around water as a resource. Important questions are: how high is the water demand? Where can the water come from? Are there (technical) options for keeping water in circulation? Can (technical or administrative) measures be taken to tap "additional" (non-revenue) water or to use alternatives to fresh water?

The fact that educational initiatives such as the cooperation between the German-Jordanian University and the University of Applied Sciences Würzburg-Schweinfurt have already been launched to train the relevant know-how in the country can be seen as an important step towards securing plant operation in the long term and raising socio-economic potential in the country. However, attention must be paid to the entire ecosystem, including compression, storage, transport and application of hydrogen.

Finally, the topic should always be discussed from the perspective of social acceptance. Ideally, the establishment of a hydrogen economy is a social consensus. However, since water is a resource that is essential for survival and a hydrogen economy can compete with current water needs, preliminary studies and pilot projects should be carried out to examine more closely what possibilities exist for increasing acceptance among the population.

6 | Lists and bibliography

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6.2 List of figures

6.3 List of abbreviations, units and symbols

Abbreviations	
AEL	Alkaline electrolysis
AFD	Agence Française de Développement (French Development Agency)
AHK	Chamber of Commerce
BHKW	Combined heat and power plant
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BOO	Build-Own-Operating
BOT	Build-Operate-Transfer
COP	Conference of the Parties
dena	German Energy Agency
EBRD	European Bank for Reconstruction and Development
EDCO	Electricity Distribution Company
EMRC	Energy and Minerals Regulatory Committee
EPC	Engineering, Procurement, Construction
F&E	Research and development
FPV	Floating Photovoltaic
GEEREF	Global fund of funds for energy efficiency and renewable energies
GIZ	Society for International Cooperation
GJWHD	German-Jordanian Water-Hydrogen Dialogue
HTEL	High-temperature electrolysis
IDECO	Irbid District Electricity Company
IEA	International Energy Agency
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
JBIC	Japan Bank for International Cooperation
JEPCO	Jordan Electric Power Company
JUST	Jordanian University of Science and Technology
KfW	Reconstruction Loan Corporation
LNG	Liquefied natural gas
MEMR	Ministry of Energy and Mineral Resources
MENA	Middle East and North Africa
MWIDE	Ministry of Economic Affairs, Industry, Climate Protection and Energy of the State of North Rhine-Westphalia
NEPCO	National Electric Power Company
OFID	OPEC Fund for International Development
OPEC	Organisation of Petroleum Exporting Countries
ÖPNV	Public transport
PEMEL	Polymer electrolyte membrane electrolysis
PHES	Pumped Hydroelectric Energy Storage
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PtX	Power-to-X
PV	Photovoltaics
RSS	Royal Scientific Society
SUNREF	Sustainable Use of Natural Resources and Energy Finance

Units and symbols	
CO_2	Carbon dioxide
EUR	Euro
GW	Gigawatt
GWp	Gigawatt peak
H_2	Hydrogen
H_2O	Water
kg	Kilogram
km^2	Square kilometre
ktoe	Kiloton of oil units
m^3	Cubic metres
m.	Million
MW	Megawatt
MWh	Megawatt hour
O_2	Oxygen
TWh	Terawatt hours

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