A North Africa - Europe Hydrogen Manifesto

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Dii Desert Energy
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Dii Desert Energy Vision

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Towards a fully emission free energy supply in MENA before 2050 and making MENA a ‘power house’ for the global energy markets offering benefits to the region

Strategy

Connecting the international industry active in the MENA region with authorities and institutions. Focus on practical conditions for ‘green electrons’ and ‘green molecules’ along the energy value chains leading to tangible and profitable projects and other benefits for local and international stakeholders

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SUMMARY

A joint hydrogen strategy between Europe and North Africa can help build a European energy system based on 50% renewable electricity and 50% green hydrogen by 2050.

For Europe, the green hydrogen shall consist of hydrogen produced in Europe, complemented by hydrogen imports, especially from North Africa. Hydrogen produced in North Africa will be beneficial for both Europe and North Africa. A bold energy sector strategy with an important infrastructure component is suggested, which differs from more traditional bottom-up sectoral strategies. This approach guarantees optimized use of (existing) infrastructure, has low risk and cost, improves Europe's energy security and supports European technology leadership. In North Africa it would foster economic development, boost export, create future-oriented jobs in a high-tech sector and support social stability.

This paper is a summary of the chapter Hydrogen, the Bridge between Africa and Europe in the book "Shaping an Inclusive Energy Transition" (M.P.C. Weijnen and Z. Lukszo (editors), Frank Wouters, Ad van Wijk), Springer (2020), complemented with valuable insights in recent developments in the green hydrogen space in Morocco.

INTRODUCTION

Green hydrogen made from renewable electricity and water will play a crucial role in our decarbonized future economy, as shown in many recent scenarios.

In a system soon dominated by variable renewables such as solar and wind, hydrogen links electricity with industrial heat, materials such as steel and fertilizer, space heating, and transport fuels. Furthermore, hydrogen can be seasonally stored and transported cost-effectively over long distances, to a large extent using existing natural gas infrastructure. Green hydrogen in combination with green electricity has the potential to entirely replace hydrocarbons.

Today, electricity comprises some 20% of final energy demand, including feedstock and international transport. About 80% of final energy demand are molecules, mainly fossil fuels. A small percentage is heat. The share of electricity in final energy demand is expected to grow 2.5 times until 2050, still leaving a large requirement for green molecules across all sectors. There are few alternatives to hydrogen, if any, to fully replace hydrocarbons in a decarbonized energy system, so electricity and hydrogen will both play an important role as energy carriers in the 2050 energy system. Therefore, a 50%-50% share split of green electricity and green hydrogen in Europe's final energy demand is proposed for all sectors: industry, transport, commercial and households.

Due to its limited size and population density, Europe will not be able to produce all its renewable energy in Europe itself. Therefore, it is assumed that a large part of the hydrogen will be imported. Although hydrogen import can come from many areas in the world with good solar and wind resources, an interesting possibility is the import from North Africa. Already today, according to OPEC and EIA, 13 % of the natural gas and 10 % of the oil consumed in Europe comes from North Africa, and 60 per cent of North Africa's oil exports and 80 % of its gas exports are sent to Europe.

North Africa has good solar and wind resources and many countries are developing ambitious renewable energy strategies to cater for growing energy demand of urban and industrial centers, but also electrify the unserved parts of the population in remoter areas. Low-cost and price-stable renewable electricity has the potential to spur economic growth, necessary to stabilize societies and reduce economic migration. However, over and beyond catering for domestic demand, most North African countries have huge potential in terms of land and resources to produce green hydrogen from solar and wind for export. The resources in North Africa are vast, only 8% of the Sahara Desert covered with solar panels is required to produce 155.000 TWh, all the energy the world requires (van Wijk, van der Roest, & Boere, 2017).

When Europe and North Africa develop a joint hydrogen economy, both North Africa and Europe will benefit. Like natural gas, hydrogen can be imported from North Africa by pipeline, which is more cost effective than import by ship. With hydrogen imported from North Africa, Europe could realize a sustainable energy system, required to meet the obligations of the Paris Agreement, faster and cheaper. Furthermore, a joint European - North African renewable energy and hydrogen approach would create economic development, future-oriented jobs and social stability in North-African countries, potentially reducing the number of economic migrants from the region to Europe.

RENEWABLE ENERGY RESOURCES IN EUROPE AND NORTH AFRICA

In Europe, good renewable energy resources are geographically distributed. However, they are not evenly distributed among the EU member states and therefore large scale, pan-European energy transport and storage is necessary.

Large scale on- and offshore wind can be produced at competitive and subsidy free prices in several parts of Europe. Large scale offshore wind has great potential in the North Sea, Irish Sea, Baltic Sea and parts of the Mediterranean Sea. And large-scale onshore wind potential can be found especially in Greece, the UK, Ireland and in many other coastal areas in Europe such as Portugal, Poland and Germany. Large scale solar PV can also be built competitively and subsidy-free, most notably in Southern Europe, for instance in Spain, Italy and Greece.

Furthermore, low cost hydropower electricity can be produced in Iceland, Norway, Sweden, Austria, Switzerland, etc. and geothermal electricity in Iceland, Italy, Poland and Hungary. Although, the potential expansion of the hydropower and geothermal capacity is limited, the future introduction of marine/tidal energy converters could furthermore augment the production of renewable electricity and hydrogen in the UK, Portugal, Norway and Iceland.

In North Africa, however, the solar energy resources are even better than in Southern Europe. The Sahara Desert is the world's sunniest area year-round. It is a large area (more than 3 million square miles) that receives, on average, 3,600 hours of sunshine yearly and in some areas 4,000 hours. This translates into solar insolation levels of 2,500-3,000 kWh per square meter per year (Varadi, Wouters, & Hoffmann, 2018).

Also, the Sahara Desert is one of the windiest areas on the planet, especially on the west coast. Average annual wind speeds at ground level exceed 5 m/s in most of the desert and reach 8-9 m/s in the western coastal regions. Wind speeds also increase with height above the ground, and the Sahara winds are quite steady throughout the year (Varadi, Wouters, & Hoffmann, 2018). Also, Egypt's Zaafarana region is comparable to Morocco's Atlantic coast, with high and steady wind speeds, critical for the economics of wind energy as the energy derived from a wind turbine scales at the third power of the speed of the air passing through its blades. In Morocco, Algeria and Egypt certain land areas have wind speeds that are comparable to offshore conditions in the Mediterranean, Baltic Sea and some parts of the North Sea.

Large scale solar PV, Concentrating Solar Power and wind can be realized in North African countries against production cost lower than in Europe. The expectation is that solar PV and wind onshore production cost in North Africa will come down to 1 $ct/kWh before 2030.

Energy in Europe

Energy is used for heating, mobility, electricity and in industry for high temperature heat and as a feedstock. In 2017, the total energy consumption (Gross Available Energy) in the European Union amounted to almost 20,000 TWh, with final energy consumption, the energy consumed by end users, was about 13,000 TWh, of which 21% was electricity. The European Union is a net energy importer, with 55% of the 2017 energy needs met by imports, consisting of oil, natural gas and solid fuels. Given the population density and comparatively limited potential for renewable energy, the expectation is that Europe shall continue to import energy, also in a future renewable energy system. However, instead of fossil fuels, over time Europe shall import energy in the form of green electrons, but especially in the form of green molecules.

To achieve the binding Paris Agreement, Europe's electricity sector needs to be fully decarbonized by 2050 and other energy sectors to a large extent also. Several scenarios have looked at how to achieve this and comparing these scenarios, some 2,000 GW of solar and 650 GW of wind energy capacity must be installed by 2050, generating roughly 2,800 TWh of solar energy and 2,000 TWh of wind energy per year.

Energy in North Africa

The Southern Mediterranean countries can currently be divided in net energy importing and net energy exporting countries. Libya and Algeria have built their economies on the back of their substantial oil and gas reserves, whilst Morocco has always had to import fossil fuels. Egypt's recent offshore gas finds are expected to make the country a net natural gas exporter, joining Algeria and Libya. In the African context, in North Africa less than 2% of the population is without access to electricity. In contrast, 50% of people in West Africa and 75% in East Africa lack access to electricity. With the exception of South Africa, in Southern Africa most people lack access to electricity. North Africa on average consumes eight times more electricity per capita than the rest of the continent, excluding South Africa. (source: IRENA - Africa 2030)

IRENA's REMAP 2030 study analyzed options for the doubling of renewable energy supply by 2030 in a bottom-up approach. Supported by the excellent solar and wind resource in North Africa, it showed a feasible potential of almost 120GW by 2030, of which 70GW would be wind and the remainder a combination of CSP and PV.

An interesting example is Morocco, which has embarked on an ambitious renewable energy program with a target of 42% of renewable electricity by 2020, which was recently expanded to 52% by 2030, which corresponds to around 11GW of solar, wind and hydropower. In Ouarzazate, a beautiful city south of Morocco's High Atlas Mountains, known as a gateway to the Sahara Desert and also known from “Game of Thrones”, Morocco built the Noor solar complex, consisting of CSP and PV projects, totaling 582 MW at peak when finished. The scale of these projects and Morocco's clever financial engineering, have brought down the cost of in particular CSP, which is now competitive with conventional power.

HYDROGEN IN EUROPE AND NORTH-AFRICA

Green hydrogen can be produced in electrolysers using renewable electricity, can be transported using the natural gas grid and can be stored in salt caverns and depleted gas fields to cater for seasonal mismatches in supply and demand of energy (HyUnder, 2013). Like with natural gas, underground storage would be seasonal, while line-packing flexibility provides some short-term storage. It should be noted that blue hydrogen, hydrogen produced from fossil fuels with CCS, can play an important role in an intermediate period, helping kickstart hydrogen as an energy carrier alongside the introduction of green hydrogen.

Production cost of hydrogen

Renewable electricity is rapidly becoming cheaper than conventional electricity made in nuclear, gas- or coal-fired power plants. Already to date, solar power in Southern Europe and offshore wind in the North Sea can be sold at market prices. In North Africa, the electricity production cost of solar and wind are even lower than in Europe.

In January 2019, Morocco announced bids of € 28 per MWh for an 850MW wind farm. The expectation is that electricity production cost will further drop to € 10-20 per MWh before 2030 at sites with good solar and wind resources throughout North Africa. Combinations of solar and wind, or even wind alone, will have load factors of 4,000-5,000 hours per year. With electrolyser efficiencies of 80% (HHV, higher heating value) and CAPEX of € 300 per kW, the levelized cost of hydrogen production will be about € 1 per kg.

In Europe, however, with higher electricity production cost for solar and wind than in North Africa, the hydrogen production cost is expected to be € 0,5-1,0 per kg higher than in North Africa by 2030. But in 2050, with lower electricity production cost, higher electrolyser efficiencies and lower CAPEX the hydrogen production cost will come down to € 1 per kg in Europe too. However, the production cost in North Africa, in 2050 will also drop and be well below € 1 per kg.

Power-To-X in Morocco

Since COP22 in 2016, Power-to-X has been gaining traction in the Moroccan climate change agenda and the country now aims to be a leading international hub for the production and export of high added-value green molecules, including green hydrogen, ammonia and methanol.

Morocco has a proven track record in exploiting its renewable resources thanks to the successful deployment of large scale solar (+700MWe), wind (+1700MWe) and hydro (+1800MW) power plants. The iconic solar complex of Ouarzazate is an example of the achievement of the kingdom in this regard. This success was mainly due to strong domestic political support, as well as deep and longstanding international partnerships, enabling innovative funding schemes. The Institut de Recherche en Energie Solaires et Energies Nouvelles (IRESEN) succeeded in prioritizing PtX on the agenda of the Moroccan Ministry of Energy and Environment's. Furthermore, IRESEN has a key role in supporting academic and research efforts advancing the green hydrogen agenda in Morocco.

Morocco is engaged in an industrial acceleration program that has helped develop innovative and complex value chains such as car and aircraft industries. Related to PtX, Morocco possesses strong public and private companies able to develop a consistent 'vertical' ecosystem in this sector. The OCP Group for example, a public company and world leader in exporting phosphate-based fertilizers, is one of the leading actors in the PtX space, together with other national and international companies.

Figure 1 shows how the green hydrogen R, D&D is embedded in the national green energy agenda.

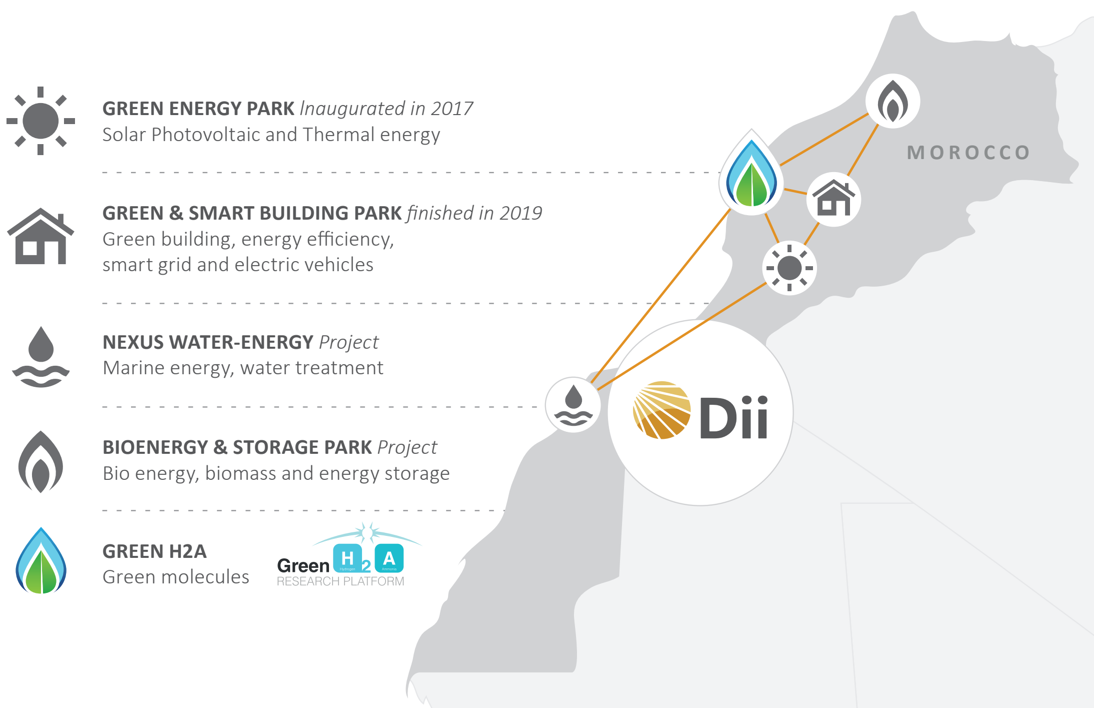
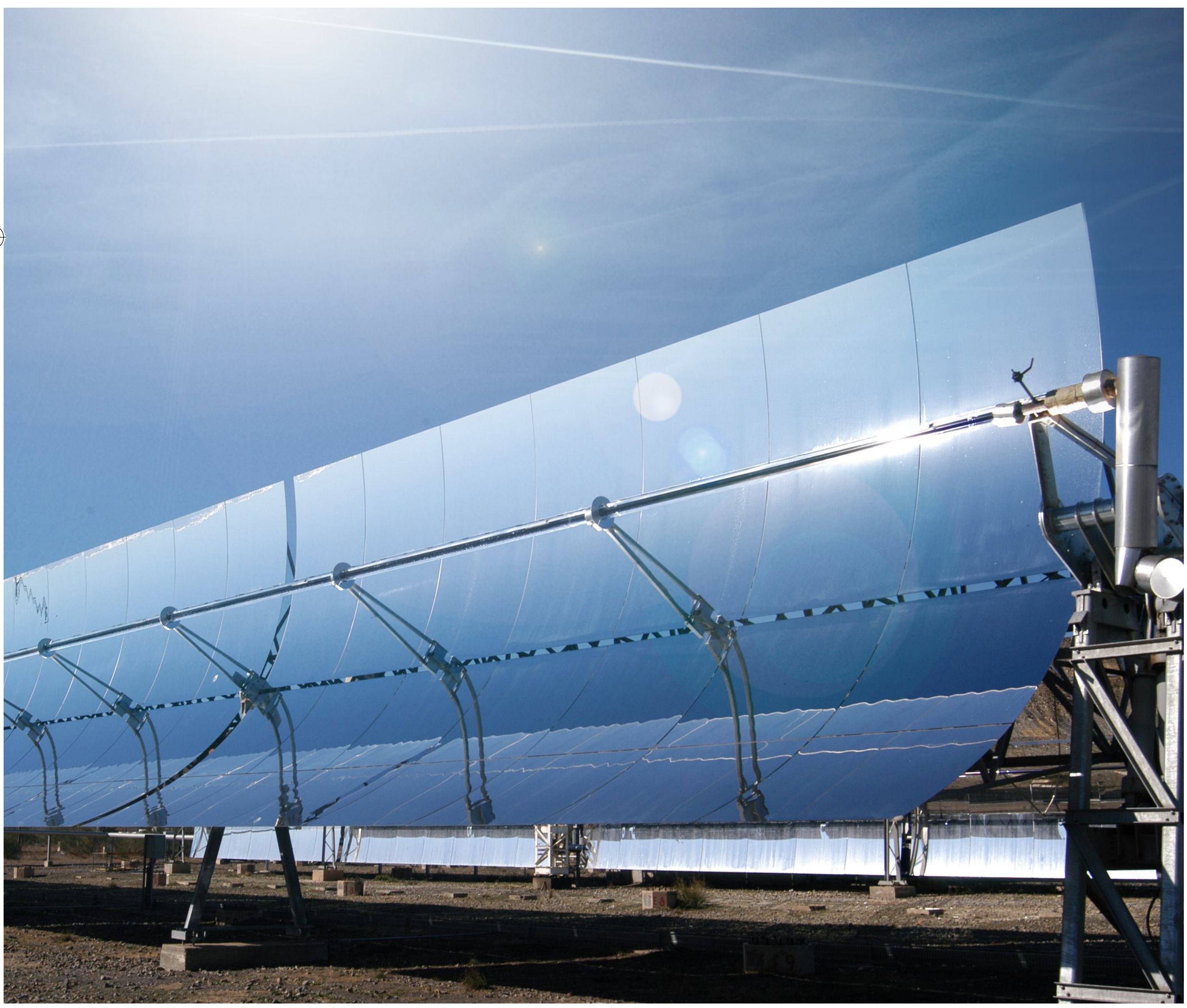


Figure 1 *Overview of current green hydrogen initiatives in Morocco*

In 2018, IRESEN, with the support of the GIZ-PAREMA, assessed that Morocco can take up to 4% of the global PtX market by 2030, given the country's exceptional renewable resources, and its successful track record in deploying large scale renewable plants (Eichhammer, 2019). Such encouraging preliminary results have led to the creation of a national committee on PtX in 2019, headed by the Ministry of Energy. This committee is currently elaborating a roadmap for hydrogen and PtX in Morocco, which will be published in 2020.

Several R&D pilot scale PtX projects are currently ongoing, and early discussions are taking place concerning scale-up possibilities. The idea is to develop commercial size plants capable of producing green molecules at a competitive price. The size would be around ~100 MW with a production capacity of around ~100kT of green molecules per year.



Infrastructure in Europe

A gas grid is much more cost-effective than an electricity grid: for the same investment, a gas pipe can transport 10-20 time more energy than an electricity cable. Also, Europe has a well-developed gas grid that can be converted to accommodate hydrogen at minimal cost. So instead of transporting bulk electricity throughout Europe, a more cost-efficient way would be to transport green hydrogen and have a dual electricity and hydrogen distribution system. Figure 2 shows the existing European natural gas grid (blue) and a hydrogen backbone (orange) as suggested by Hydrogen Europe. Such a hydrogen backbone would link the areas of low-cost renewable electricity with the load centers in Europe. Operational by 2030-2035, it could be the first phase to realize a full conversion from natural gas to hydrogen by 2050.

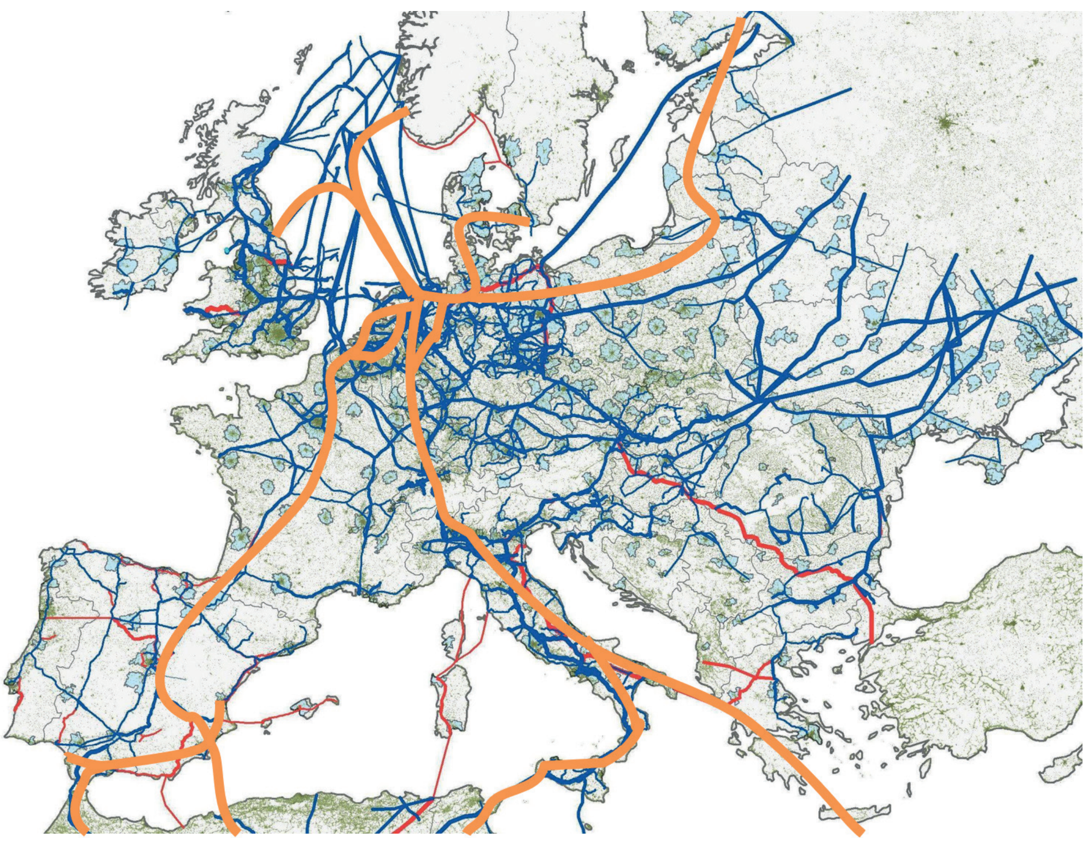


Figure 2 *Natural gas infrastructure in Europe (blue and red lines) and first outline for a hydrogen backbone infrastructure (orange lines). The main part of the hydrogen backbone infrastructure consists of re-used natural gas transport pipelines with new compressors. A new pipeline from the solar and wind resource areas in Greece needs to be realized.*

Infrastructure between Europe and North Africa

The energy ties between Europe and the countries of North Africa are very strong. Today, 13 per cent of the gas and 10 per cent of the oil consumed in Europe comes from North Africa, and over 60 per cent of North Africa's oil and gas exports are sent to Europe (Eurostatgas, 2019).

The electricity grid infrastructure requires major reinforcements and expansion in the coming decades, especially to transport electricity from the good solar and wind resource areas to the demand centers in the cities and rural areas. Today, there is only one electricity grid connection between Europe and North Africa, the 700 MW grid interconnector between Spain and Morocco. In the beginning of the century, the Desertec vision proposed to produce large amounts of solar and wind electricity in North Africa and expand the interconnection between Africa and Europe, enabling the export of part of this electricity to Europe across the Mediterranean. The cost to build such an electricity grid was huge, so even with lower production cost in North Africa, it was difficult for the imported electricity to compete with solar and wind electricity produced in Europe. However, Desertec has evolved and the vision described in this paper fits the Desertec 3.0 vision of pursuing a mutually beneficial emission-free, affordable and secure energy system consisting of green electrons and molecules.

However, there is a gas transport infrastructure available between North Africa and Europe, transporting gas from Algeria and Libya to Europe via Italy and Spain. The gas transport volume through these pipelines is over 63.5 bcm per year, which equals a capacity of more than 60 GW (Timmerberg & Kaltschmitt, 2019).

In a first phase, between 2030-2035, the natural gas infrastructure could be used to transport hydrogen from North Africa to Europe. In an initial phase, a substantial hydrogen volume can be produced by converting natural gas to hydrogen, whereby the CO2 is stored in empty gas/oil fields (blue hydrogen). Over the years however, with ever declining cost of renewable electricity and electrolyzers, more and more green hydrogen from solar and wind electricity can be fed into these pipelines.

Next to converting existing pipeline infrastructure, new hydrogen gas pipeline infrastructure could be built, connecting the good solar and wind resources in North Africa to Europe. A first new pipeline could be realized to connect Egypt and Greece to the main European gas grid in Italy, see Figure 3.

The realization of a hydrogen ''South-Nord-stream'' from Egypt, via Greece to Italy with a length of 2,500 km and with a similar capacity as the actual Nordstream, with 66 GW capacity, consisting of 2 pipelines of 48 inch each, would imply an investment of € 16.5 billion. With a load factor of 4,500 hours per year, an amount of 300 TWh or 7.6 million ton hydrogen per year can be transported. The levelized cost for hydrogen transport by such pipeline amounts to 0.005 €/kWh or 0.2 €/kg H2, which is a reasonable fraction of the total cost of delivered hydrogen.

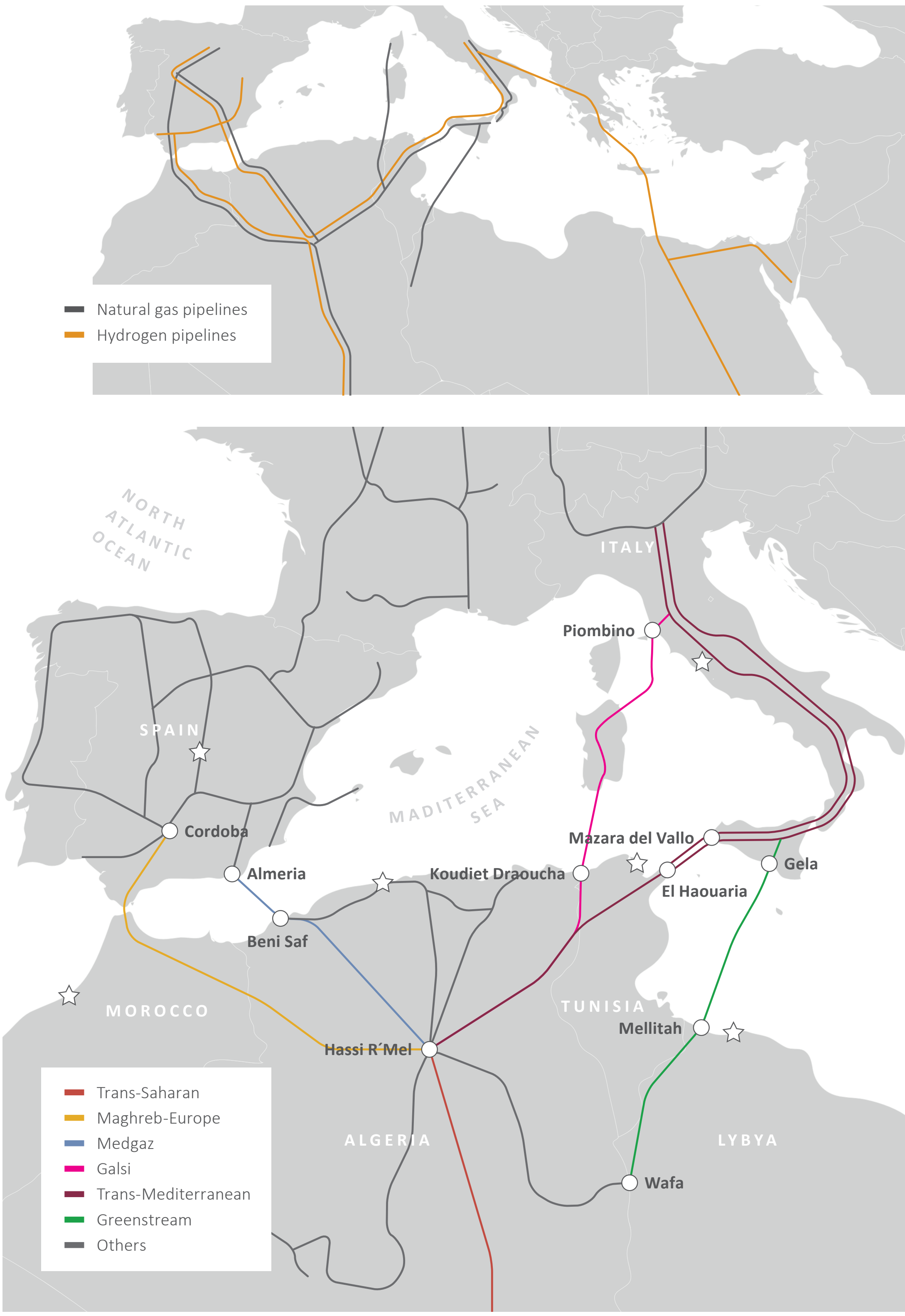


Figure 3 *Natural gas infrastructure Europe - North Africa (bottom figure) and first outline for a hydrogen backbone infrastructure Europe-North Africa (upper figure) An existing gas infrastructure from Algeria and Morocco could be converted to a hydrogen infrastructure (grey-orange lines). A ''new'' hydrogen transport pipeline must be realized from Italy to Greece, crossing the Mediterranean Sea to Egypt, which could eventually be extended to the Middle East (orange line).*

Hydrogen Storage

Electricity supply and demand needs to be balanced at any moment in time. Balancing the electricity system today is mainly done using pumped hydropower and by flexible power plants, especially gas fired power plants. Natural gas storage is therefore crucial today in balancing electricity supply and demand. But an even larger seasonal gas storage volume is needed to balance gas production and supply for space heating. Natural gas demand in Europe, especially in Northern Europe, shows a strong seasonal variation, in wintertime, the gas demand is 2-3 times higher than in summertime. However, natural gas production is constant throughout the year. Therefore, large scale seasonal storage of natural gas is necessary. Natural gas is stored in empty gas fields, porous rock formations and salt caverns. The current gas storage capacity amounts to 871TWh and is 18% of total gas consumption in Europe.

In a future energy system, the share of electricity from variable sources such as solar and wind in the overall energy supply will dramatically increase. Although the share of electricity is expected to grow to 50% of all final energy demand, green molecules will be necessary for applications that are difficult or expensive to electrify. Due to the variability of renewable energy sources and the large fluctuations in energy demand for space heating and electricity, storage capacity is needed on an hourly, daily, weekly and seasonal scale. Capacitors and batteries will play a significant role for hourly and daily storage. For large scale, seasonal and weekly storage, hydrogen storage, replacing natural gas storage, will become crucial.

Several studies have analyzed the need for hydrogen in an electricity system that is increasingly based on renewable energy sources. When electricity systems are fully based on renewable energy sources, some 20% of variable electricity must be converted to hydrogen to guarantee a secure energy supply every time of the day and year.

Hydrogen can be stored in salt caverns. There is a huge potential for hydrogen storage in salt caverns all over Europe. Total onshore salt cavern storage capacity is 23,200 TWh of which 7,300 TWh could be developed taking into account a maximum distance to the shore of 50 km, called the constrained storage capacity. This maximum limit is set for the brine disposal. The offshore storage capacity is even larger than the onshore capacity, 61,800 TWh. It should be noted that the salt cavern storage capacity potentials are even larger than total final energy consumption in Europe. Although not studied so far, a substantial potential for hydrogen storage in salt caverns is available in North Africa too.

A DIFFERENT APPROACH

By 2050 when Europe's energy system is largely based on variable renewables, hydrogen is indispensable for transport and storage. Electricity demand will increase up to 2050, but there is a need for green molecules too. And, in an electricity system based on renewable energy resources, the need for hydrogen for storage and providing balancing power is evident.

The shares of hydrogen, presented in recent scenarios are by no means the maximum levels, nor do they represent the optimum. Several scenarios have tried to estimate the increasing demand for green hydrogen in Europe over time, most recently in the Hydrogen Roadmap by the Fuel Cells and Hydrogen Joint Undertaking (FCHJU, 2019). This Roadmap estimates that hydrogen could comprise 2,250 TWh or 24% of Europe's total final energy demand including feedstock in 2050, using a gradual phasing-in approach. Similar to other bottom-up scenarios, the inherent difficulty lies in predicting adoption rates of a new product in new markets, which invariably leads to conservative estimations, mostly well below hydrogen's potential.

A different approach is proposed to realize a sustainable and inclusive energy system. A sustainable energy system that is reliable, secure, affordable, accessible and fair. But above all, could be realized cheaper and faster than presented in recent scenarios by the EU and others. This approach could therefore offer a more realistic pathway for a climate-neutral and fully renewable energy system in the European Union by 2050.

1. Re-use gas infrastructure
2. Develop hydrogen storage
3. 50-50-50; final energy demand in 2050, 50% electricity and 50% hydrogen
4. Europe needs North Africa for green hydrogen

1. Re-use Gas-Infrastructure

Similar to the introduction of electricity and natural gas 100 and 50 years ago, instead of a gradual phasing in of green hydrogen, a more ambitious approach based on infrastructure development is proposed. The fundamental philosophy is to make green hydrogen available at scale and cost-effectively and replace fossil fuels as quickly as possible by repurposing the current natural gas infrastructure to carry green hydrogen. Since the transmission and distribution infrastructure is already to a large extent available, the focus can be on developing electrolyser capacity, which is an opportunity for European market leadership. Hydrogen's intrinsic quality as a transport fuel, its ubiquitous characteristics in industrial processes and ability for storage and long-range transport will lead to a rapid market uptake in Europe. Initially a combination of blue and green hydrogen would be required to produce enough volume to convert a meaningful part of the European gas transport infrastructure. Over time blue hydrogen would be phased out and replaced by green hydrogen.

Of course, the electricity grid needs to be expanded and drastically modernized too, when a 50% share of electricity in final energy use is foreseen. However, the capacity in the electricity transport grid today is about 10 times less than the capacity in the gas transport grid. Besides, the cost for converting the gas grid to hydrogen will cost much less, most probably a factor of 100 less, than building new electricity transmission grid capacity. And the natural gas grid, to a large extent, already exists, facilitating a much faster integration of renewable resources. A smart combination of expanding the electricity grid and at the same time re-using and expanding the gas grid for hydrogen will contribute to a cheaper energy infrastructure, at the same time realizing a renewable energy system faster.

2. Develop large-scale hydrogen storage

In 2050, when the energy system is based on renewable energy sources, an assumed storage capacity of about 20%-30% of final energy consumption is needed. Salt caverns can provide enough hydrogen storage capacity for this, catering for seasonal storage but also to keep a strategic energy reserve.

Large-scale, seasonal and strategic energy storage can be provided by salt caverns relatively cheaply. However, battery storage will provide shorter term storage; hourly and daily storage and frequency control services for the electricity system can be provided by electrochemical batteries. But also, smart grids, demand side management, strengthening interconnections and other balancing instruments will be necessary to operate the electricity system reliably and cost-efficiently.

3. 50-50-50; 2050 final energy demand split in 50% electricity and 50% hydrogen

Europe's final energy demand including feedstock and energy for international transport (shipping and aviation), is estimated to be 12,000 TWh by 2050, based on an analysis of above-mentioned scenarios. If a similar division in energy use between the sectors is assumed as in 2017 (Eurostat, 2017), the final energy use per sector for 2050 is shown in Table 1.

Sector	TWh/a (2050)	Share (2017)
Industry Energy	2,500	21 %
Industry Feedstock	1,300	11 %
Transport in EU	3,100	26 %
Transport international	700	6 %
Commercial and Services	1,500	12 %
Households	2,700	22 %
Other	200	2 %
Overall	**12,000**	**100 %**

Table 1 *Share of EU Final Energy use per sector*

Today, electricity comprises less than 20% of final energy demand, including for feedstock and international transport. About 80% of final energy demand are molecules, mainly fossil fuels. A small percentage is heat. The share of electricity in final energy demand is expected to grow 2.5 times until 2050, still leaving a large requirement for green molecules across all sectors. There are few alternatives to hydrogen, if any, to fully replace hydrocarbons in a decarbonized energy system, so electricity and hydrogen will both play an important role as energy carriers in the 2050 energy system. Therefore, a 50%-50% share split of green electricity and green hydrogen in Europe's final energy demand is proposed for all sectors: industry, transport, commercial and households.

4. Europe needs North Africa for green hydrogen

Given a final energy demand of 12,000 TWh in 2050, with a 50%-50% split between electricity and hydrogen, the question is:

"How and where can we produce the necessary energy by renewable resources?"

About 2,000 GW solar and 650 GW wind, together with hydropower and other renewable energy resources, could produce 5,000 TWh electricity in 2050. Green hydrogen needs to be produced using additional green electricity over and beyond the 2,000 GW solar and 650 GW wind capacity. Far offshore wind in the North Sea, Baltic Sea, Mediterranean Sea and in the Atlantic Ocean can produce cost-competitive green hydrogen by transporting this hydrogen to the shore by pipeline. Next to this, wind combined with solar on good locations in Southern Europe (Spain, Italy, Portugal and Greece) could produce cost-competitive hydrogen too.

However, a substantial part of the necessary hydrogen needs to be imported from neighboring regions. Europe currently import a substantial part of its energy from Russia. However, North Africa, where green hydrogen can be produced at lower cost than in Europe and transported through cost-effective pipelines, requires due consideration.

Green hydrogen can be imported by ship as liquid hydrogen, ammonia (NH3) or methylcyclohexane (MCH, hydrogen bound to toluene), from additional sources further away, like LNG nowadays (IEA, 2019). But at distances below 4,000 km, shipping is more expensive than pipeline transportation (Lanphen, 2019).

Energy supply and demand need to be balanced at all time. The large seasonal fluctuations in energy demand, especially for space heating, and the variability of solar and wind, require large scale storage capacity. We assume that 20% of the final energy demand, both for electricity and hydrogen, needs to be supplied via hydrogen energy storage. 1,200 TWh final electricity demand must therefore be supplied by electricity production from stored hydrogen. This electricity can be produced by fuel cells, placed close to the demand centers. Expensive electricity transport cost will be avoided and the excess heat from these fuel cells could be used for space heating, if feasible.

An Energy Balance can be constructed, considering storage and losses, see Figure 4. The necessary primary energy (electricity) to deliver 12,000 TWh final energy demand, is then 15,710 TWh. This yields an overall system efficiency of 76%, a little better than today's 72%. However, in a fully renewable energy system, not based on finite energy sources, this efficiency figure loses relevance. In the future, it is not about system efficiency, but about system cost.

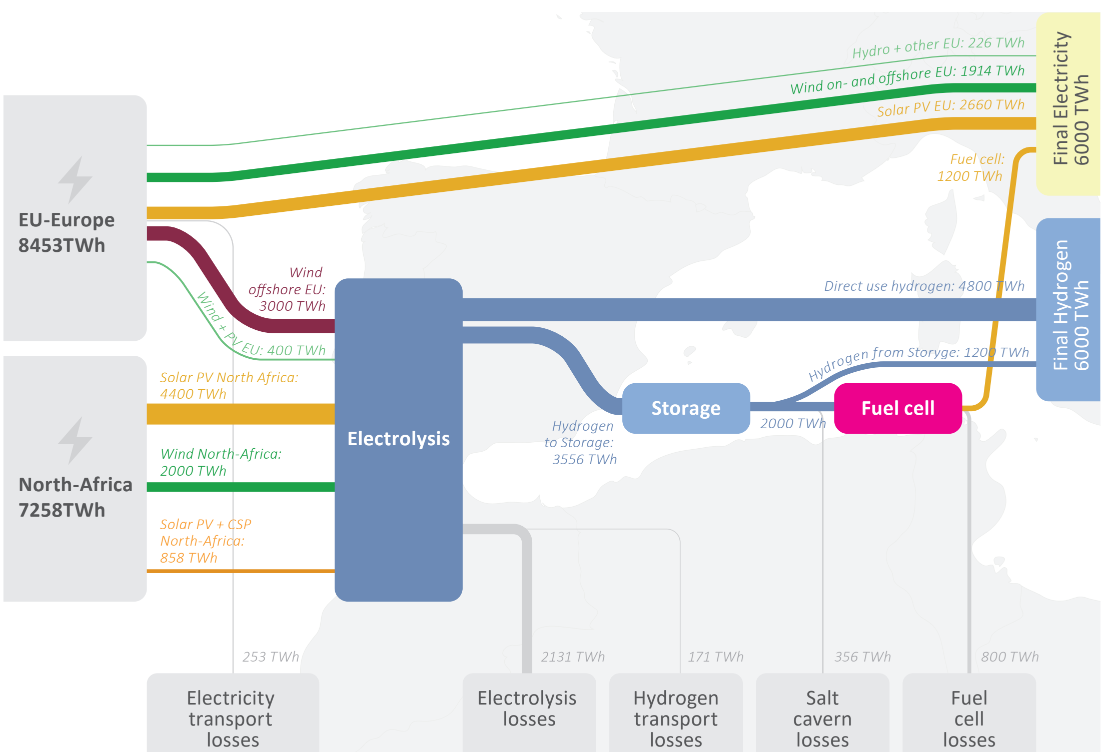


Figure 4 *Energy Balance European Union 2050; primary energy production is 15,710 TWh, with final energy consumption amounting to 12,000 TWh.*

From this 15,710 TWh primary energy production, 8,450 TWh, 54%, is produced in Europe and 7,260 TWh, or 46%, is produced in North Africa. It should be noted that this is a marked improvement over our current situation, where Europe imports 55% of its primary energy demand. Considering the annual hydrogen production, 8,520 TWh in total, more than 2/3 needs to be imported from North Africa, see Table 2. It clearly shows that for a fully renewable energy system in Europe, we need North Africa to produce cost-competitive solar and wind electricity, converted to hydrogen, for export by pipeline to Europe.

2050 Primary energy production	Electricity Capacity GW	Electricity production TWh	Hydrogen production TWh	Hydrogen production Mton H_2
Europe				
Solar PV	2,000	2,800		
Wind (onshore + offshore)	650	2,010		
Hydro + other renewables		240		
Additional Offshore Wind for Hydrogen	600	3,000	2,400	61
Additional Wind + Solar PV for Hydrogen	100	400	320	8
Total Europe		**8,450**	**2,720**	**69**
North Africa				
Solar PV	2,000	4,400	3,520	89
Wind (onshore)	500	2,000	1,600	41
Solar PV + CSP (hybrids)	170	860	690	17
Total North Africa		**7,260**	**5,810**	**147**
Total		**15,710**	**8,530**	**216**

Table 2 *Primary energy production in Europe and North Africa, for use in the EU in 2050*

What needs to be done?

Such a renewable energy scenario for Europe, implies a massive program to realize renewable energy capacity both in Europe and in North Africa. About 4,200 GW solar capacity and 1,800 wind capacity needs to be realized. To appreciate the scale of investment, the current installed capacity of all coal fired power plants in the world amounts to 2,000 GW. For conversion from electricity to hydrogen, about 3,400 GW of electrolyser capacity is needed. And for the conversion from hydrogen to electricity, about 500 GW of fuel cell capacity needs to be installed, see Table 3.

Next to this, the pipeline capacity between North Africa and Europe needs to be expanded to about 1.000 GW, which is about 30 pipelines with a capacity of 33 GW each. In Europe the gas pipeline infrastructure is partly available. However, the production flows of hydrogen are, to a large extent, from the south to the north. This means that, especially from the south of Europe to the north of Europe, the hydrogen gas grid needs to be expanded. In Europe the electricity transport infrastructure needs to be considerably expanded.

Final electricity consumption in 2017 was about 3,000 TWh and will be doubled in 2050. On a volume basis, the capacity therefore needs to be expanded with at least a factor of 2. However, especially the grid capacity from the north and south of Europe to the load centers and the interconnections between the European countries. needs be expanded much more than a factor of 2, see Table 3.

The estimated large-scale storage volume in this scenario is 3,630 TWh or 92 million ton hydrogen. One salt cavern can store about 6.000 ton of hydrogen. So, there is a need for 15,000 salt caverns for hydrogen storage. Although these salt caverns can be realized in Europe, also in North Africa salt cavern storage capacity needs to be realized. One third of the salt cavern capacity needs to be realized in North Africa. Next to this there is a need for battery storage, especially for day-night storage and heat and cold storage, especially seasonal storage in aquifers, see Table 3.

An important aspect of this transition is that the end-use conversion technologies need to be replaced. It means e.g. the replacement of all present internal combustion engine vehicles by electric vehicles, both battery and hydrogen fuel cell electric vehicles. But also replacing existing heating equipment in houses, with heat pumps, hydrogen boilers or fuel cells. However, this equipment is typically replaced every 10-15 years anyhow. Therefore in 30 years' time the replacement of this equipment is manageable.

2050 What needs to be done	To be realized in 2050 (to cater for Europe's energy demand)
Production	
Solar capacity	**4,200 GW;** 2,000 GW Europe and 2,200 GW North Africa
Wind capacity	**1,800 GW;** 1,300 GW Europe and 500 GW North Africa
Conversion	
Electrolyser Capacity	**3,400 GW;** 700 GW Europe and 2,700 GW North Africa
Fuel cell Capacity	**500 GW;** in Europe
Infrastructure	
Hydrogen pipelines	**1,000 GW** pipeline connection between Europe and North Africa. Re-use existing gas pipeline infrastructure in Europe and North Africa, conversion from natural gas to hydrogen Expand pipeline capacity, especially from south to north of Europe. Realize pipeline connections between North African countries from east to west.
Electricity grid	Massive capacity expansion of the electricity grid, at least with a factor 2 on a volume base Grid re-enforcement and new grids are required between the renewable electricity production in Northern and Southern Europe and the load centers. Capacity expansion of interconnections between countries. Realize an electricity grid in and between North African countries
Storage	
Salt caverns	**15,000** Salt caverns; 10,000 in Europe, 5,000in North Africa Hydrogen storage in empty gas fields if possible
Batteries	Batteries are required, especially for day-night storage; North Africa could rely much more on battery storage than on hydrogen storage, due to its climatological conditions
Heat storage	Seasonal heat and cold storage for space heating, especially in aquifers and rock formations. This is important for North-Europe

TOWARDS A SUSTAINABLE AND INCLUSIVE ENERGY SYSTEM

An inclusive energy transition is about an energy system that is affordable, accessible, secure, reliable and fair (distribution of benefits and burdens) for everyone. A 50% renewable electricity and 50% renewable hydrogen system developed in mutual co-operation with North Africa for the benefit of both, whereby everyone is connected to an energy infrastructure including energy storage facilities (electricity, hydrogen), is a good prerequisite for an inclusive energy system.

Affordable

Renewable electricity is rapidly becoming cheaper than conventional electricity made in nuclear, gas- or coal-fired power plants. Already to date, solar power in Southern Europe and offshore wind in the North Sea does not require subsidy but can be produced and sold at market prices. If a green hydrogen market would develop along the lines sketched here, hydrogen can be produced at € 1 per kg, which is compatible with natural gas prices of €9/mmbtu or €0.25/m3. Since the energy content of 1 kg of hydrogen is equivalent to 3.8 liter of gasoline, it is also cheaper than gasoline or diesel at that price point, even discounting the tax on transport fuels.

The advantage of a mutual co-operation with North Africa are two-fold: the economic opportunity for North African economies, and the lower production cost for hydrogen from solar and wind electricity. The resources are better, investment cost lower and space is abundantly available. Hydrogen could be produced for less than € 1 per kg and be competitive with hydrogen produced in Europe, even including pipeline transportation cost.

But the main advantage lies in the infrastructure and storage. The proposed transition would, to a large extent, use the existing natural gas grid and would avoid an expensive and troublesome complete overhaul and large capacity expansion of the electricity grid. Also, storage, especially large-scale seasonal storage for hydrogen can be realized similar to natural gas, in existing and newly realized salt caverns. Hydrogen storage in salt caverns can not only be realized much cheaper, it can be realized faster too.

An affordable energy system for everyone is not necessarily a system where energy is produced, stored and consumed locally. Especially renewable energy resources show a great variation in production cost around the world. At places with good solar irradiation or wind speeds and cheap land and competitive labour cost, the production cost could be a factor 5-10 lower than at places with moderate solar irradiation or wind speeds, and high land and labour costs. Also, large scale energy storage costs (hydrogen in salt caverns or ammonia in large tanks), are easily a factor of 100 cheaper than small scale storage costs (compressed hydrogen in bottles or electricity in batteries). Therefore, an affordable energy system for everyone will be a smart combination of a large scale and local energy system.

Accessible

An accessible energy system for everyone is a system whereby everyone has access to clean energy. An important pre-requisite for access to clean energy is a connection to a well-organized energy infrastructure. This could be an electricity, gas or heat grid or a fuelling infrastructure, whereby an electricity grid connection is the most essential one. A combination with a gas infrastructure (hydrogen), especially in Europe, is in many cases useful to deliver the necessary energy for heating at moments of high demand.

The connection to energy infrastructure needs to be guaranteed. This could be achieved by obliging energy transport and distribution companies to connect every consumer and every producer. The question is whether the cost for such a connection needs to be socialized. This seems to be a fair principle, making it possible that all consumers are not only connected to an energy infrastructure, but also could afford to pay for it. The obligation to connect and socializing energy infrastructure cost seems a good principle, but how to implement these principles in a fully renewable energy system, with electricity and hydrogen as the main energy carriers? Two type of questions arise: connecting to which infrastructure and socializing over what energy? We illustrate these questions with two examples, informing the debate for policy makers.

- If a far offshore wind farm is realized, is there an obligation to connect to an electricity grid or can the wind farm owner choose to connect to either the electricity or the hydrogen grid. Or can the energy transport companies (TSO's) together decide to connect to a hydrogen grid and/or an electricity grid?
- If the natural gas infrastructure is converted to a hydrogen infrastructure, do we socialize the cost over the hydrogen consumption only, or do we socialize these costs over the total gas (natural gas and hydrogen) consumption. Or do we have to socialize cost for all infrastructure (electricity, natural gas, hydrogen) over all energy consumption.

Secure

Security of supply is always an important consideration, especially because energy is a vital part of the economy. A system described here reduces the import share of currently 55%, to a much reduced 46%, with a more diverse set of countries supplying Europe. The infrastructure proposed also carries important benefits for North African nations, enabling them to trade hydrogen and electricity among each other and exporting to Europe, earning foreign exchange and boosting their economies.

Reliable

To deliver energy at the right time and place, an energy infrastructure with enough transport and distribution capacity is necessary together with enough storage capacity at different time scales (seasonal, weekly, daily, hourly, minutes and seconds). An all-electric system, whereby only electricity is transported, stored and distributed, needs a gigantic and very expensive expansion of the electricity grid and battery storage capacity. In Europe especially, with seasonal storage needs due to space heating, such an all-electric system seems inhibitively expensive and almost impossible. In North-Africa, however, with less seasonal variation and where solar production matches cooling demand, an all-electric solution with battery storage to cater for the evening peak, seems a good and cost-effective solution. But demand for hydrogen for mobility and industry will also develop in North Africa.

In Europe, due to its existing natural gas infrastructure, a smart combination of a green electricity and hydrogen energy system could offer a reliable and cost-effective solution. Of course, there is a need to modernize and increase the capacity in the electricity grid, together with installing battery and capacitor capacity for frequency response and short-term storage. But especially for weekly and seasonal storage, hydrogen offers a much cheaper solution, especially by storing hydrogen in salt caverns.

Fair

The development of a clean energy system for both Europe and North Africa in mutual co-operation is beneficial for both. Europe cannot produce the renewable energy it needs in Europe alone, it simply does not have enough solar and wind resources, nor available and affordable land. North Africa on the other hand, has these resources abundantly available and can produce enough clean energy for their own demand, as well as for export to Europe and other parts of the world. But North Africa lacks the technology, capital and a well-educated labour force to develop a clean energy system on their own. Therefore, cooperation on the development of a renewable, fully decarbonized energy system is for the benefit of both. It creates future-oriented economic development, jobs and welfare in North Africa by developing a clean energy system for their own use and export. In Europe, a clean, reliable and affordable energy system can be realized by re-using part of the existing assets and infrastructure, in combination with renewable energy production in Europe and import from North Africa.
Europe can build a sustainable, circular and cost-competitive industry, based on green electricity and green hydrogen supply at competitive cost. And Europe and North Africa together could be world market leaders in renewable energy system technology and system production and realization, especially in electrolyser, gasification and fuel cell technologies, hydrogen, electricity and heat storage technologies, energy infrastructure and conversion technologies, green chemistry and synthetic fuels.

Improving livelihoods in Africa will reduce the migration of people from Africa, seeking economic opportunities in Europe. The joint development of a clean energy system could provide a perspective on a better life and future in these North African countries. Such a development is fair from both European and North African perspective.

CONCLUSIONS AND NEEDED POLITICAL AGENDA.

A European energy system based on 50% green electricity and 50% green hydrogen, developed in mutual co-operation with North Africa for the benefit of both, would have many advantages:

- The energy system would be entirely clean, with no CO_2 emissions, which meets the Paris Agreement but would also have tremendous health benefits due to reduced local emissions in European and African cities.
- The system would be a shift away from a system based on finite resources, which invariably leads to scarcity and higher cost towards the end, to a system entirely based on renewable energy resources with technologies becoming cheaper over time.
- A European ambition level based on proven but largely undeveloped technologies (electrolysers, gasifiers, fuel cells, hydrogen storage technologies, new domestic appliances, hydrogen-electric mobility, synthetic green chemicals and fuels) provides a tremendous opportunity for global technology leadership, with associated economic momentum and job creation.
- The infrastructure required for the new system will be largely based on the already existing natural gas grid and avoids an expensive overhaul and massive capacity expansion of the electricity grid.
- The energy system would be reliable, with balanced supply and demand at all time and every place, due to large-scale, cheap hydrogen storage, especially in salt caverns, together with a public hybrid electricity-hydrogen infrastructure.
- Developing a clean energy system in cooperation between Europe and North Africa, unlocks access to vast and cheap renewable energy resources for Europe and North Africa, whilst supporting the development of affordable, reliable and clean energy for North Africa itself.
- Europe and North Africa can both profit from this cooperation, it creates economic development, new business, new export, jobs and welfare in North Africa as well as in Europe
- Developing a clean energy system in North Africa, for own use and export, creates jobs, welfare and better living conditions reducing the necessity for people to migrate to Europe.

However, such a "moonshot" program requires tremendous political and societal will on a level rarely required, not only within Europe but also between Europe and North Africa. To enable the transition and avoid the exclusion of large parts of the current energy industry, careful thought must be given to minimize stranded assets and include as many players as possible. An environment for investments in Europe and North Africa needs to be designed, in mutual co-operation, for the benefit of both.

The following are necessary considerations for an action agenda:

- A strong, clear and lasting political commitment is necessary, embedded in a binding European strategy with clear goals stretching over several decades.

- A new type of public private partnership on a pan-European level must be crafted, with the aim to create an ecosystem to nurture a European clean energy industry that has the potential to be world leaders in the field. This partnership should include existing energy industry, as well as innovative newcomers.

- A novel enabling regulatory environment and associated market design is required for the necessary investments, whilst keeping the system costs affordable.

- An integrated electricity-hydrogen infrastructure and storage system policy framework needs to be designed, with fair access to energy for everyone.

- Finally, above all a new, unique and long-lasting mutual cooperation on political, societal and economic level between the EU and North Africa needs to be designed and realized. This cooperation needs to be based on mutual respect and trust, considering each other's cultural, social and economic backgrounds.

References

BP. (2019). *BP Energy Outlook, 2019 edition.*

Bundesnetzagentur. *(2019, May). Quartalsbericht zu Netz- und Systemsicherheitsmaßnahmen; Gesamtjahr und Viertes Quartal 2018. Retrieved from https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2019/Quartalsbericht_Q4_2018.pdf?__blob=publicationFile&v=4*

Carbon Capture and Storage, A. (2019). *Retrieved from http://www.ccsassociation.org/faqs/ccs-globally/*

Dii, & FraunhoferISI. (2012, May 22). *Desert Power 2050 Perspectives on a Sustainable Power System for EUMENA. Presented at SWP Berlin.*

DNVGL. (2017). *Verkenning waterstofinfrastructuur (in Dutch). Rapport for Ministery of Economic Affairs.*

DNV-GL. (2018). *Energy Transition Outlook 2018, a global and regional forecast of the energy transition to 2050. Retrieved from https://eto.dnvgl.com*

Eichhammer, W. e. (2019). *STUDY ON THE OPPORTUNITIES OF "POWER-TO-X" IN MOROCCO. Fraunhofer ISI.*

EuropeanCommission. (2018). *A Clean Planet for all; A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Brussels.*

Eurostat. (2019, February 7). *Retrieved from https://ec.europa.eu/eurostat/documents/2995521/9549144/8-07022019-AP-EN.pdf/4a5fe0b1-c20f-46f0-8184-e82b694ad492*

EurostatEnergy. (2019). *EU28 Energy Balances February 2019 edition. Retrieved from https://ec.europa.eu/eurostat*

Eurostatgas. (2019). *Natural gas supply statistics; Consumption trends. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_supply_statistics#Consumption_trends*

EurostatGuide. (2019, Januari 31). *Energy Balance Guide Draft. Retrieved from https://ec.europa.eu/eurostat/documents/38154/4956218/ENERGY-BALANCE-GUIDE-DRAFT-31JANUARY2019.pdf/cf121393-919f-4b84-9059-cdf0f69ec045*

EWEA. (2017). 2050: *Facilitating 50% Wind Energy. Retrieved from http://www.ewea.org/fileadmin/files/library/publications/position-papers/EWEA_2050_50_wind_energy.pdf*

FCHJU. (2019). *Hydrogen Roadmap Europe, a sustainable pathway for the european energy transition. Retrieved from https://fch.europa.eu*

HydrogenCouncil. (2017, November). *Hydrogen scaling up; a sustainable pathway to the global energy transition. Retrieved from http://hydrogencouncil.com/study-hydrogen-scaling-up/*

HyUnder. (2013). *Assessment of the potential, the actors and relevant business cases for large scale and seasonal storage of renewable electricity by hydrogen underground storage in Europe . EU report 14-8-2013 www.fch.europa.eu.*

IEA. (2019). *The Future of Hydrogen, seizing today's opportunities. Report prepared by the IEA for the G20 Japan.*

Jülich. (2019). *Hydrogen storage in Salt Caverns. To be published.*

Kiwa. (2018). *Toekomstbestendige gasdistributienetten (in Dutch). Rapport for Netbeheer Nederland.*

Lanphen, S. (2019). *Hydrogen Import Terminal; Providing insights in the cost of supply chain of various hydrogen carriers for the import of hydrogen. MsC thesis, TU Delft, Delft.*

Michalski, J., Bünger, U., Crotogino, F., Donadei, S., Schneider, G., Pregger, T., & al, e. (2017). *Hydrogen generation by electrolysis and storage in salt caverns: Potentials, economics and systems aspects with regard to the German energy transition. International Journal of Hydrogen.*

Morgan, S. (2019, March 5). *Five EU countries call for 100% renewable energy by 2050. Retrieved from https://www.euractiv.com/section/climate-strategy-2050/news/five-eu-countries-call-for-100-renewable-energy-by-2050/*

Nordstream. (2017). *Factsheet The Nordstream Pipeline Project. Retrieved from https://www.nord-stream.com/*

Ram, M., Bogdanov, D., Aghahosseini, A., Oyewo, A. G., Child, M., Fell, H.-J., & Breyer, C. (2017). *Global Energy System based on 100% Renewable Energy - Power Sector. Study by Lappeenranta University of Technology and Energy Watch Group, Lappeenranta, Berlin.*

Shell. (2018). *Shell scenario SKY, meeting the goals of the Paris agreement. Retrieved from https://www.shell.com/skyscenario*

Timmerberg, S., & Kaltschmitt, M. (2019). *Hydrogen from renewables: Supply from North Africa to Central Europe as blend in existing pipelines - Potentials and costs. Applied Energy 237, 795-809.*

van Wijk, A., van der Roest, E., & Boere, J. (2017). *Solar Power to the People. Nieuwegein-Utrecht: Allied Waters.*

Varadi, Wouters, & Hoffmann. (2018). *The Sun is Rising in Africa and the Middle East - On the Road to a Solar Energy Future. Singapore: Pan Stanford Publishing Co ISBN-10: 9814774898 .*

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