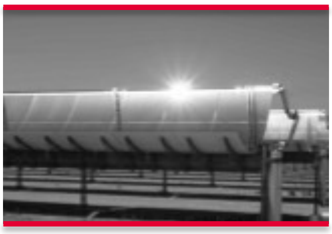
MENA FUELS

Sub-report 14 | November 2022

Synthesis and courses of action – report on results of the MENA-Fuels project

Report from the
subproject B.III: Synthesis

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Please cite the report as follows:

Viebahn, P., Kern, J., Horst, J., Rosenstiel, A., Terrapon-Pfaff, J., Doré, L., Krüger, C., Zelt, O., Pregger, T., Braun, J., Klann, U. (2022). Synthesis and courses of action. Report on results of the MENA-Fuels project. Sub-report 14 to the Federal Ministry for Economic Affairs and Climate Action (BMWK). Wuppertal Institut, German Aerospace Center (DLR), Institut für ZukunftsEnergie- und Stoffstromsysteme (Institute for Future Energy and Material Flow Systems, IZES). Wuppertal, Cologne, Stuttgart, Saarbrücken

Acknowledgements

This report was prepared as part of the research project **MENA-Fuels – Roadmaps for the Generation of Sustainable Synthetic Fuels in the MENA Region for the Decarbonisation of Traffic in Germany**. It is supplemented by additional published reports. The publishers wish to thank all of the participating research institutes, the funding provider and its project executing organisation as well as the external experts from science and industry for their constructive collaboration and valuable contributions to this publication.

Disclaimer

The research project on which this report is based was carried out with funding from the Federal Ministry for Economic Affairs and Climate Action (BMWK) under subsidy file number 3EIV181A-C. The authors bear responsibility for the content of this report.

The maps appearing in this report are intended as illustrations only. They do not constitute any official statement on the part of the Federal Republic of Germany regarding any controversial legal positions of third countries.

Project duration: December 2018–June 2022

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Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

izes gGmbH Institut für ZukunftsEnergie- und Stoffstromsysteme

Wuppertal Institut

Legal notice

Publisher:

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Image sources:
Title page: Getty Images
Back page: own illustration

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List of abbreviations, units and symbols

Abbreviations

ADV	‘100% renewable energies scenario’ for MENA countries
AEL	alkaline electrolysis
ALOP	environmental impact category for agricultural land occupation
ALT	‘alternative moderate renewable energies strategy’ scenario for MENA countries
ALT2	‘ALT variant with 100% synthetic fuels in 2050’ scenario
bau, B.A.U.	business as usual
BMWK	Federal Ministry for Economic Affairs and Climate Action
CC	carbon capture
CEBC	MENA Clean Energy Business Council
CED	cumulative energy demand
Co-HTE	high-temperature co-electrolysis
COP	Conference of the Parties
CPA	cost-potential analysis
CPs	cost-potentials
CSP	concentrated solar power
DAC	direct air capture
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e. V.)
DME	dimethyl ether
EL	innovative drives scenario – development of demand with a strong focus on efficiency and electric vehicles
EnDAT	energy data analysis tool
ESM	energy supply model
ESM-I	energy supply model – invest module
EU	European Union
EUMENA	Europa, Middle East and North Africa
EUR	euro
FM	fuel mix scenario – development in demand with balanced use of energy sources in the transport sector
FM_bau	FM_risk_business-as-usual
FM_neg	FM_risk_challenging
FM_pos	FM_risk_positive
FT	Fischer-Tropsch
GHG	greenhouse gas
GWP	global warming potential (climate change environmental impact category)
HT	high temperature
HTE	high-temperature electrolysis
HVDCT	high-voltage direct current transmission
IEA	International Energy Agency
IWES	Fraunhofer Institute for Wind Energy Systems
IZES	IZES gGmbH – Institut für ZukunftsEnergies- und Stroffstromsysteme (Institute for Future Energy and Material Flow Systems)
LCA	life cycle analysis
LCA	life cycle assessment
LOHC	liquid organic hydrogen carriers
LSCA	large-scale commercial availability
LT	low temperature
MtDME	methanol-to-dimethyl ether
MtG	methanol-to-gasoline
MtK	Methanol-to-kerosene
MtOME	methanol-to-polyoxymethylene dimethyl ether
OME	polyoxymethylene dimethyl ether
OSeMOSYS	Open Source energy MOdelling SYStem

Abbreviations

PEM	proton exchange membrane
PPA	power purchase agreements
PtL	power-to-liquid
PV	photovoltaics
RE	renewable energies
ReCiPe	a harmonised eco-balance assessment method
RED II	EU Renewable Energy Directive
REF	reference scenario
RWGS	reverse water gas shift
SEEGIOM	Socioeconomic and Environmentally Extended Global Input-Output Model
SOEL	solid oxide electrolyser
SYN	classic drives scenario – development of demand with a strong focus on synthetic fuels
Synfuels	synthetic fuel, used here as a synonym for synthetic combustibles, fuels, propellants and raw materials for the industrial sector
TRL	technology readiness level
VC	value chain
WACC	weighted average cost of capital
WI	Wuppertal Institut für Klima, Umwelt, Energie gGmbH (Wuppertal Institute for Climate, Environment and Energy)
WISEE	Wuppertal Institute System Model Architecture for Energy and Emission Scenarios

Abbreviations - Countries and regions

DE	Germany
DZ	Algeria
EG	Egypt
IL	Israel
IQ	Iraq
IR	Iran
JO	Jordan
LB	Lebanon
LY	Libya
MA	Maghreb minus Tunisia and Algeria
MENA	Middle East and North Africa
NA	North Africa
OM	Oman
QA	Qatar
SA	Saudi Arabia
SY	Syria
TN	Tunisia
UAE	United Arab Emirates
UAE (AE)	United Arab Emirates
YE	Yemen

Units and symbols

%	per cent
°C	degree Celsius
€	euro
a	annum
bn	billion
CH_4	methane
CO_2	carbon dioxide
GJ	gigajoule
h	hour
H_2	hydrogen
H_2O	water
km	kilometre
l	litre
m	million
NMVOC	non-methane volatile organic compounds
NO_x	nitrogen oxide
PJ	petajoule
PM	particulate matter
SO_2	sulphur oxide
t	tonnes
TW	terawatt
TWh	terawatt-hours

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1 Introduction

By adopting the Paris Agreement in 2015, the COP21 United Nations Climate Change Conference agreed to limit global warming to well below 2°C. This treaty calls for the rapid global development of strategies and solutions aimed at effectively implementing greenhouse gas (GHG) reduction pathways. In, 2021, Germany adopted a law under which the country is to be climate neutral by 2045. This requires that, in addition to transitioning its energy sector, Germany's transport and industrial sectors also need to fully convert to a climate-neutral economic approach (Bundesregierung, 2021). As a result, the transport sector in particular needs to make a significantly greater effort and implement more effective strategies aimed at decarbonisation and defossilisation[1] due to its high rates of GHG emissions and minimal successes in reducing these emissions thus far.

Thus far, there is no across-the-board solution for developing the mobility sector in Germany and Europe in line with the relevant targets going forward. In addition to behaviour-related activities aimed at reducing transport activities (particularly those involving the most energy-intensive transport modes), two technical strategies are of key relevance in this context – one being the *direct electrification* of transport based on renewable energies (electric mobility) and the other being *indirect electrification* using gaseous and liquid fuels produced from green hydrogen (i.e., based on renewable energies); these fuels are referred to as 'synthetic fuels'[2]. While electric mobility achieves a high degree of efficiency with the use of renewable energies, synthetic fuels permit the ongoing and continued use of the vehicle fleet and the existing distribution and tank infrastructure without interruption. However, the drawback of such fuels is the high energy losses incurred during their production due to the numerous conversion steps involved. Another potential under discussion consists of combining the two solutions – that is, using synthetic fuels in aviation, shipping and heavy goods traffic while also making the shift to electric mobility in passenger transport.

Another aspect to consider is the decarbonisation or defossilisation of the industrial sector. Strategies based on the *indirect use of renewable energies* are advantageous in the energy intensive industry in particular, which produces high levels of GHG emissions (Agora Energiewende and Wuppertal Institut, 2019). These strategies involve the use of green hydrogen, e.g. in the steel industry (direct reduction) and the chemicals industry as well as the use of 'green feedstock'; that is, raw materials that are likewise produced on the basis of green hydrogen but also offer potential for the transport sector (such as the intermediary product methanol). Synergies or competition between the transport and industrial sectors should thus be taken into account from the outset.

Depending on the strategy, the question arises as to how and at what costs the demand for electricity from renewable energies (RE), hydrogen and its synthetic

[1] In contrast to decarbonisation, the term defossilisation is used when, as in the case of fuels, hydrocarbons ('carbon') continue to be used, with the difference being that they can no longer be derived from fossil sources (petroleum, natural gas).

[2] In addition to this, methods are also being developed for producing hydrogen without diverting it via green electricity; this would involve using sunlight or concentrated heat for the water splitting process (solar fuels).

downstream products (synthetic fuels or raw materials) can be met. Significant quantities of RE are required for the production of downstream products in particular. Given that the process of generating electricity from RE makes up approx. 50 per cent of the overall production costs, the origin of the RE is a key variable. This energy can be sourced either directly from Germany, from Europe or from sunny and windy regions outside Europe. Various regions are being discussed in terms of non-European imports, including Australia, Brazil, China, Chile, California, the Middle East and North and South Africa. The relation between domestic production and imports of RE, hydrogen and its synthetic downstream products has been the subject of heated debate in recent years, but clear answers and strategies for solutions have yet to be identified.

The MENA-Fuels research project tackled this question and analysed it in a broader methodological context. The MENA region (Middle East/North Africa) was selected as a potential import region in this context due to the fact that (1) it is located in close geographical proximity to Europe and also Germany, (2) it offers extensive potential for renewable energies, (3) the region has growing political significance for Germany and Europe, (4) Germany already shares trade relationships with many countries in the region and (5) the region has significant potential for socio-economic development.

The project's **key research question** was:

> *What role could the MENA region play in supplying Germany (and Europe) with green synthetic combustibles and fuels, feedstocks or their precursors?*

The project analysed the potentials available in the individual countries and regions, the costs at which the corresponding resources could be made available, the transport infrastructure that is required, which sections of the value chain (VC) are located in the MENA region and which in Germany, the long-term demand for hydrogen and its synthetic downstream products in the MENA region itself or which competitors are to be expected outside of MENA and Europe.

By analysing the new trade relationships that could develop between the MENA region and Germany (and Europe), the study provides *insights that serve as guidance* for projects considering the MENA region as a potential key trade partner for hydrogen and its synthetic downstream products and that have the capacity to make decisions regarding the long-term use of resources with greater confidence based on the results derived from the research.

On the other hand, the study does not make any statements on short and mid-term decisions regarding investments in the region due to its systemic analytical approach and the long-term perspective taken in the research. Another factor to be considered is that the presented results are based solely on technological/economic modelling, and that no analyses were conducted regarding the actual implementation of projects at the local level.

2 Concept and approach in MENA-Fuels

2.1 Content of the sub-projects

The research project consisted of four complementary sub-projects (see Fig. 2-1), the results of which are compiled in this synthesis report and assessed as regards the overarching research question.

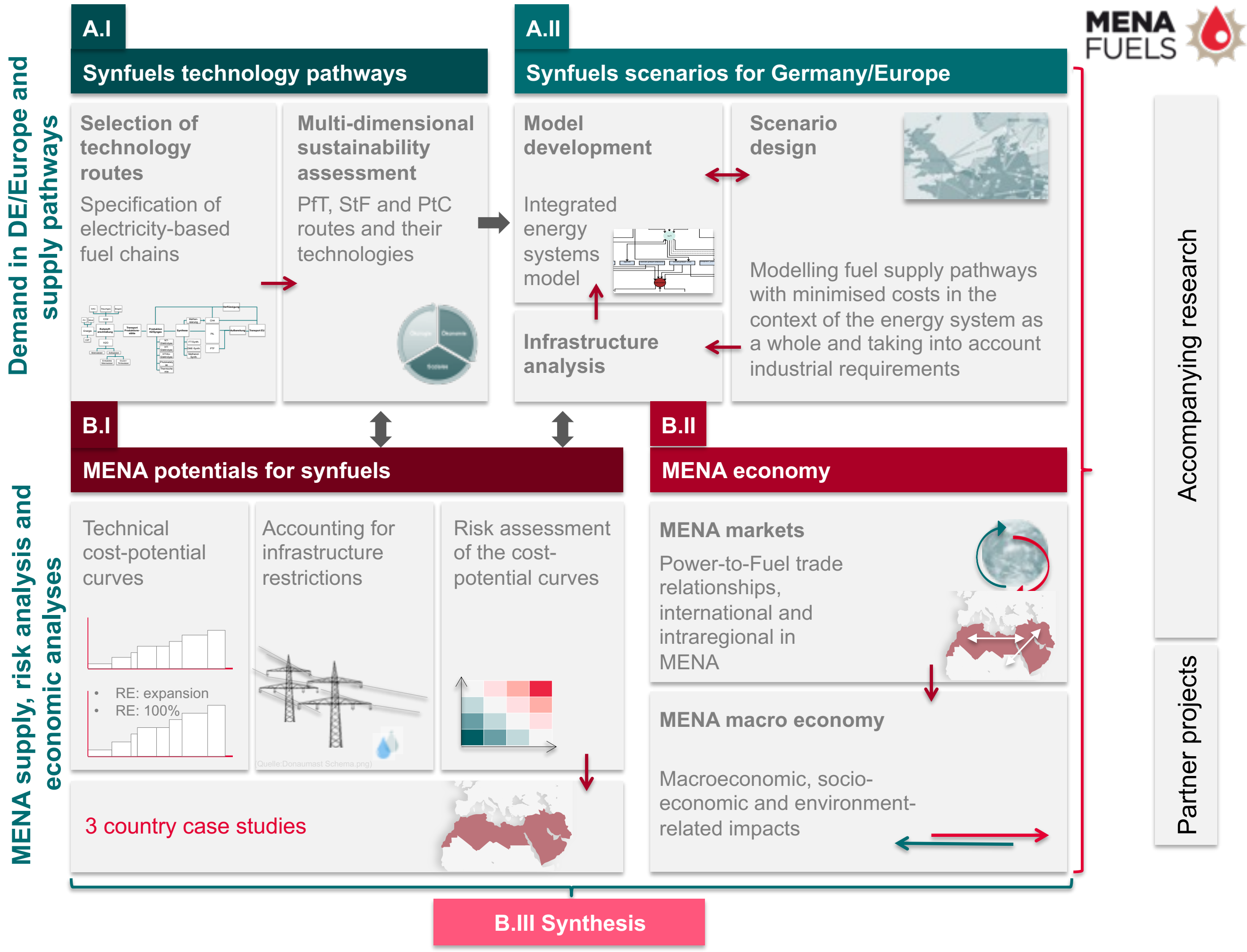


Fig. 2-1 Components of the MENA-Fuels study

Source: Wuppertal Institut

Sub-project A: Demand for RE electricity, hydrogen and its synthetic downstream products and identifying cost-effective supply pathways for Germany/Europe

- Sub-project A.I addressed the development status of the technologies required for the production of synthetic fuels and feedstocks. The technologies were then assessed from a *holistic perspective* (ecological, economic, technological, system-wide) in order to pinpoint their respective opportunities, obstacles and development potential. In addition, the sub-project analysed examples of eco-balances for the production of synthetic kerosene using various routes.

- Sub-project A.II started by deriving three different *demand scenarios* for RE electricity, hydrogen and its synthetic downstream products for Germany and Europe. The demand scenarios reflect three potential developments as regards the type of drive technologies and thus the supply of energy to the transport sector; however, they are based on the same assumptions as those used for the modal split. Based on an energy supply model, *supply pathways incurring minimal costs* for Germany and Europe were then specified with these energy sources from the MENA region. The analyses, building on the export potentials identified in sub-project B.I, were carried out while accounting for country-related risks in one instance and without considering them in the other instance.

Sub-project B: Supply of RE electricity, hydrogen and its synthetic downstream products in the MENA region, risk assessment and macroeconomic evaluation

- Sub-project B.I started by specifying *cost potentials* for the use of renewable energies and synthetic fuels produced on this basis for the individual MENA countries and regions as well as assessing these potentials in terms of costs. The energy demand required by the individual countries over the long term was deducted from these technical potentials to arrive at the export potential. This figure was determined for each country via long-term scenarios for a *supply with 100 per cent renewable energies*. The analysed MENA countries and regions were assessed with respect to their *micro and macro risks* alongside this, with the risks being incorporated in the form of additional costs. This was followed by three *short studies* for selected countries (Morocco, Jordan and Oman) that looked at the general infrastructural and industrial conditions around developing an export sector for hydrogen and synthetic downstream products as well as identifying relevant stakeholders and their interests.
- The first part of sub-project B.II consisted of developing a *world trade model* that was used to analyse *trade relationships and sales markets* for green hydrogen and synthetic fuels. An interesting aspect in this context is future competitive relationships between countries outside Europe and the MENA region, due to which the potentials determined above might not be available for import to Germany. The second part of the sub-project determined the *effects relating to employment, gross value added and GHG emissions for the economy as a whole* due to the supply pathways. To this end, a *multi-regional input/output model* was applied, taking into account the various national production structures and the composition of the potential investments in both the MENA countries and in Germany.

The brief descriptions provided below make reference to the respective sub-reports of the project in which the approach and results of the individual work packages are outlined. An overview of all sub-reports (written in German) can be found on the penultimate page of this report.

2.2 Definitions

This section provides an overview of the various types of models and scenarios that were used, depending on the sub-project. These are explained in the following sections.

Models

- The **WISEE-ESM-I energy supply model** is a linear optimisation model for the long-term planning and assessment of transition pathways with maximum cost-effectiveness between Germany/Europe and the MENA region.
- A **bottom-up energy scenario model** was used to create scenarios for the various MENA countries and regions based on the projection of energy footprints.
- The **EnDAT energy data model** was utilised for an analysis of capacity and electricity generation potentials at spatial and temporal resolutions, with these potentials serving as input for energy system, technology and scenario modelling.
- A techno-economic **power-to-liquid (PTL)** model was used to determine production costs and potentials for synthetic fuels at the regional and national levels.
- The resilience of the trade relationships specified in the energy demand model was reviewed based on a **trade model**, and further potential trade partnerships with Germany, the European Union (EU) and the MENA region were identified.
- The **WI-SEEGIOM input/output model** was applied to analyse the effects of the trade relationships identified in the energy supply model from a macroeconomic perspective.

Scenarios

- The **demand scenarios** (section 4.3) map the long-term demand in Germany and Europe for RE electricity, hydrogen and its synthetic downstream products:
  - ‘Innovative drives’ (EL)
  - ‘Fuel mix’ (FM)
  - ‘Classic drives’ (SYN)
- The demand scenarios were used as the starting point for defining **basic scenarios** that model the energy system from a purely techno-economic perspective without taking into account investment risks in the MENA region. The names of these scenarios correspond to the demand scenarios on which they are based:
  - ‘Innovative drives’ (EL)
  - ‘Fuel mix’ (FM)
  - ‘Classic drives’ (SYN)
- The basic scenario (BM) serves as the starting point for three **scenario variants** that explicitly map investment risks in the MENA region by basing them on individual weighted average capital costs (WACC) for each country and vary them in the respective case (section 4.4):

  - 'FM_risk_bau' (FM_bau) based on WACC_bau (business-as-usual).
  - 'FM_risk_positive' (FM_pos) based on WACC_pos.
  - 'FM_risk_challenging (FM_neg) based on WACC_neg.
- Three **risk scenarios** map the potential future development of the risks that countries are subject to as regards the development of the RE sector and the synthetic fuel sector for each of the MENA countries considered (section 5.1):
  - 'business-as-usual', no change in risk assessment (Risk_bau).
  - 'positive risk development' (Risk_pos)
  - 'challenging risk development' (Risk_neg)
- The risk scenarios are used as the basis for determining increases in capital costs for the RE sector and the synthetic fuels sector for specific countries, with these being incorporated in the WACC (section 5.1):
  - The WACC_bau scenario based on the Risk_bau risk scenario.
  - The WACC_pos scenario based on the Risk_pos risk scenario.
  - The WACC_neg scenario based on the Risk_neg risk scenario.
  - By comparison, WACC_ref has an average WACC of 6 per cent.
- Four **energy scenarios** map the potential demand for energy and fuels for the relevant MENA countries in future (section 5.2):
  - 'Reference scenario' (REF)
  - 'Alternative moderate RE strategy' (ALT)
  - '100 % RE scenario' (ADV)
  - 'ALT variant with 100% synthetic fuels in 2050' (ALT2)
- The trade model (section 6.1) builds on the demand scenarios (BM, EL, SYN) for the European countries and the 100 per cent RE scenario (ADV) for the MENA region. Each scenario has four variants – based on the WACC scenarios WACC_bau, WACC_pos and WACC_neg and supplemented by a reference variant WACC_ref, which assumes an equal WACC of 6 per cent for all providers.

Designations

- The term EUMENA is used in contexts that consider both the MENA region and Europe.
- The following designations are used synonymously for the analysed products:
  - RE electricity, hydrogen and synthetic downstream products
  - RE electricity, hydrogen and synfuels
  - RE electricity and synthetic energy sources

  The following meanings apply in this context:

- ‘synthetic downstream products’ or ‘synfuels’: synthetic combustibles and fuels, propellants and feedstocks for industry
- ‘synthetic energy sources’: hydrogen and synfuels

Type of energy use

- This project only looks at green hydrogen and its synthetic downstream products, so the hydrogen is based on renewable energies in all cases. Hydrogen from other sources (natural gas, coal, nuclear energy, etc.) is not included in the analyses.
- In term of renewable energies, photovoltaics (PV), concentrated solar power (CSP) and wind energy are analysed in the project.
- The use of biomass is not taken into consideration. This is to avoid any competition with the food sector that would come about as a result of the scarcity of water resources, unequal distribution of precipitation and limited amounts of usable agricultural space coupled with the high demand for synthetic fuels assumed in this study (→ *sub-report 1*).
- Likewise, biomass is not considered as a source of CO_2 in this report.

2.3 Expert committees and accompanying research

In order to discuss the plausibility of the project’s assumptions and results, the initiative was supported by two advisory boards, with one consisting of industry representatives from Germany with an interest in this area (*Industrial Advisory Board*) and the other of relevant players from the MENA region (*MENA-Fuels Advisory Board*). The committees met three to four times during the course of the project and supported the consortium by providing key information and input to discussions. A list of board members can be found in the appendix.

As part of the BMWK *energy transition in the transport sector funding initiative*, the MENA-Fuels project was simultaneously involved in *BEniVer – accompanying research*, which also created the conditions for fruitful discussions on methods and assumptions.

3 Sub-project A.I: Technology assessment for synthetic fuels

3.1 Multi-criteria technology assessment

This sub-project assessed technologies for producing synthetic fuels and feedstocks, taking into account the entire fuel production chain from technologies for generating electricity and high-temperature heat using RE technologies to provide water and carbon dioxide as raw materials, to methods for producing synthesis gas and hydrogen from RE, to fuel synthesis methods such as methanol synthesis and the Fischer-Tropsch (FT) process (Fig. 3-1). The selection of fuels and delivery technologies is based on literature research carried out at the start of the project (→ *sub-report 1*).

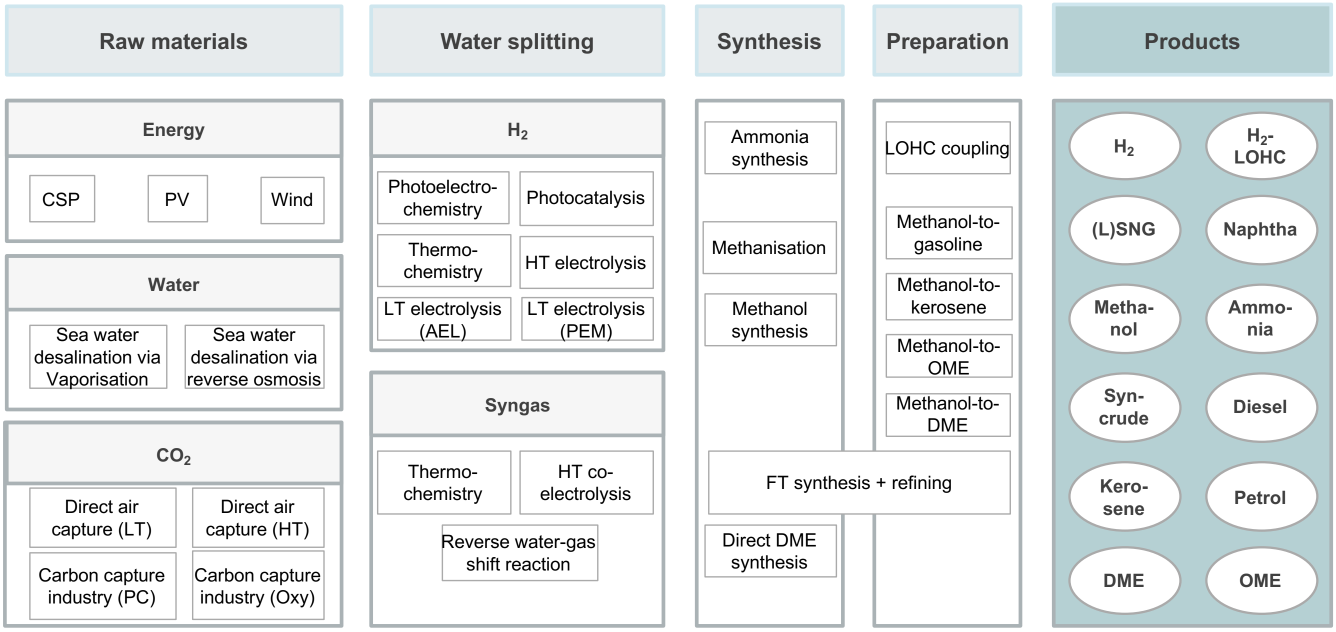


Fig. 3-1 Overview of the analysed technology groups and their modules

Each technology was analysed in light of various assessment criteria (particularly large-scale commercial availability, specific costs and energy efficiency as well as land use, requirements for critical raw materials and industrial policy opportunities for Germany). The sub-project looked at the period up until 2050 in order to take future developments into consideration as well. The assessment criteria are described in detail in → *sub-report 3* based on an assessment guide.

Assessment framework

Fig. 3-2 provides an overview of the assessment results for the seven technology groups. Please refer to → *sub-report 3* for a detailed explanation of the comparative assessments.

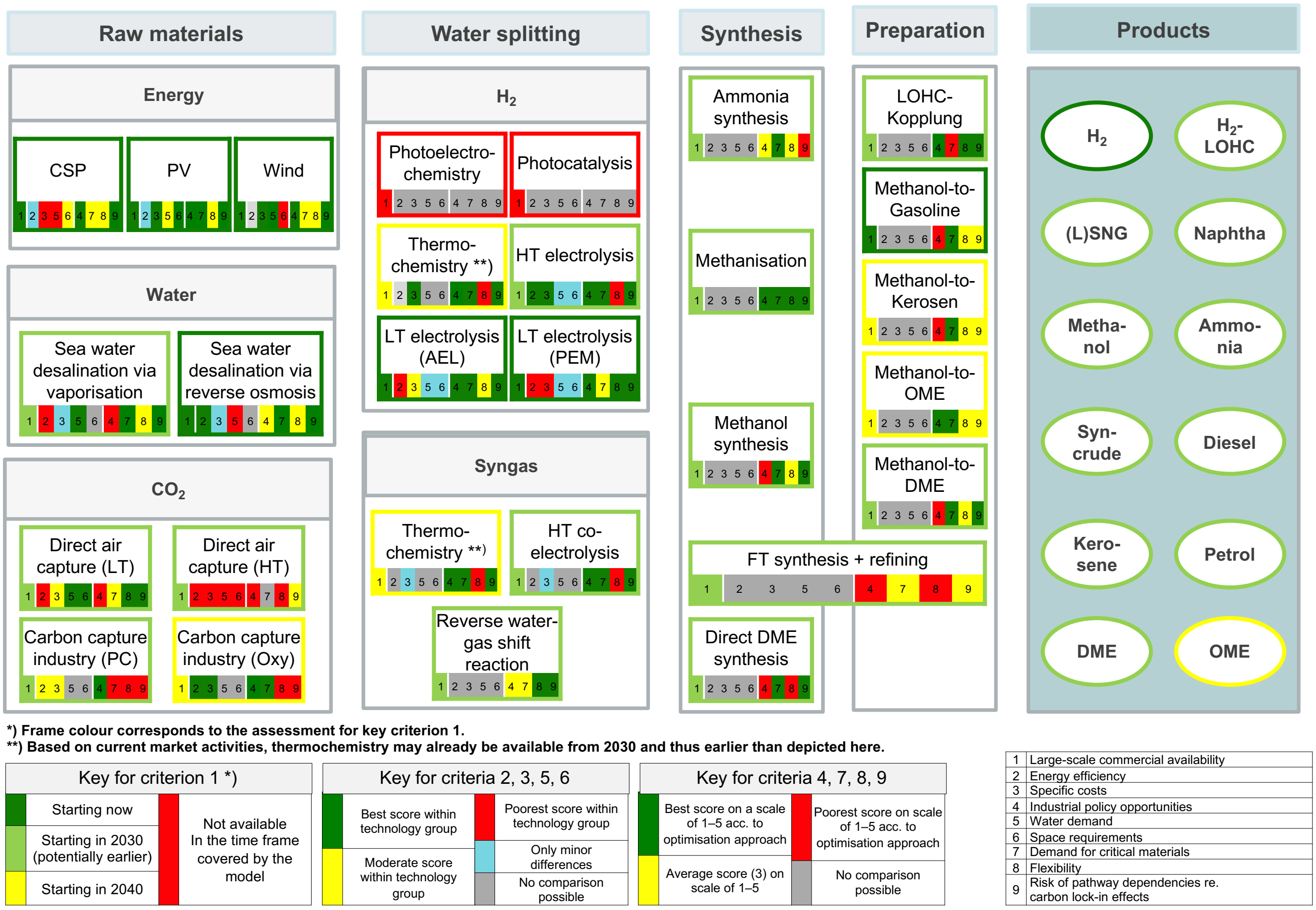


Fig. 3-2 Overview of the relative assessments in each technology group

Photoelectrochemistry and *photocatalysis* are the sole technologies that will only become available in the long term (from 2050 onwards). All of the other technologies can be taken into consideration in the modelling with their associated expected costs as well as their energy and water requirements according to the year in which they are expected to reach large-scale commercial availability (LSCA, criterion 1). The respective point in time is indicated by the colour of the frame (dark green: from 2020, light green: from 2030, yellow: from 2040). As explained in the following, it should be noted that, due to current market activities, the potential that the technologies may be available earlier than is shown in the graphic (from as soon as 2030) cannot be excluded for the *thermochemical hydrogen and synthesis gas production technologies*.

As described in further detail in → *sub-report 3*, the colouring for all the other criteria represents a *relative estimate*. If a technology is coloured in yellow or red, this therefore indicates a need for action regarding its ongoing technical development. This approach meets the project's goal of avoiding comparisons between individual technologies, instead focusing on their advantages and disadvantages as well as the potential and requirements in terms of their development. As regards the quantitative criteria 2, 3, 5 and 6 in particular, it should be noted that the respective colouring indicates the position occupied by the technology within the specified value range of a criterion for a certain technology group. Absolute statements as to whether the technology should be classified as 'good' or 'bad' for the respective criterion cannot be arrived at directly based on this information.

In addition to the technologies, the analysed products including their expected LSCA are shown on the right side of the figure (cf. the colour of the respective circles). These were derived from the corresponding LSCAs of the individual modules by using the LSCA of the most recently available module, depending on the potential production pathway. For example, synthetic kerosene should be available on a large-scale basis by 2030 using FT synthesis, while LSCA for methanol-to-kerosene (MtK) synthesis is not expected until 2040. As shown in the illustration, all of the synthetic fuels apart from polyoxymethylene dimethyl ether (OME) will be commercially available by 2030 via at least one route.

Results of the technology groups

As an example, the following statements can be made regarding individual technologies or technology groups of those considered in the project:

- All of the considered technologies for **supplying electricity and high-temperature heat** from renewable sources are ready for commercial use and are already being installed globally. When viewed in light of the analysis criteria, they appear to be non-critical to a large extent – with photovoltaics in particular offering certain advantages as regards costs and water and space requirements. This technology group involves the least challenges as regards the development of PtX process chains.
- Methods of **supplying water** via sea water desalination are ready for commercial use and installed worldwide – with reverse osmosis being the clear market leader. The challenges involved in linking this technology to RE are also assessed as lower, while the pilot and demonstration phase still needs to be completed in the coming years for the delivery of regenerative low pressure steam for the vaporisation process.
- Technologies for **carbon capture and use** are not currently ready for the market at a large scale and may therefore prove to be a bottleneck for the production of synthetic fuels. The low-temperature direct air capture (DAC) method, which can be used under various spatial conditions, is proving to be a comparatively well-developed technology that is highly beneficial in terms of the criteria under consideration. It is assumed that high-temperature DAC and industrial post-combustion capture will also be available from 2030. A replacement for the latter is expected to be available from 2040 in the form of the oxyfuel method, which meets the technical requirements for use in the cement industry more effectively in principle. However, the use of CO_2 from industrial processes generally increases the risk of pathway dependencies and carbon lock-ins.
- The results indicated that, of the methods available for producing **hydrogen** within the period under consideration in MENA-Fuels, low-temperature electrolysis has an advantage over the short term. For this reason, larger projects for producing green hydrogen will be based primarily on alkaline (AEL) and proton exchange membrane (PEM) electrolysis in the coming years. High-temperature

electrolysis (HTE) is expected to see a rapid technology ramp-up along with a sharp decrease in costs. HTE is thus set to become increasingly competitive by 2030. From a long-term perspective, HTE has the highest potential of all electrolysis technologies due to its higher degree of efficiency and the low volumes of critical raw materials required. A further advantage is that the HTE method can be used to directly generate **synthesis gas** for the production of synthetic fuels. Once high-temperature co-electrolysis (Co-HTE) reaches market maturity, this technology could also reduce future demand for multi-stage processes to produce synthesis gas via reverse water gas shift (RWGS), which, at present, are also still far from reaching market maturity at present.

- **Solar thermal cycles processes** are also capable of producing synthesis fuels directly from water and carbon dioxide. This technology was likewise found to have a high potential to offer very low costs for producing hydrogen or synthesis gas. The analysis assumed that the technology would only be implemented at industrial scale from 2040 onwards. However, current market activities indicate that this could occur significantly sooner.
- It is expected that all of the **synthesis processes** considered in the project will be available for commercial use by 2030 at the latest – in many cases, the challenge is integrating the overall process on the basis of renewable energies. Making useful comparative statements regarding the quantitative criteria considered is not possible here due to the fact that the processes supply various products with different intended uses, and there are also a number of data gaps. Methanisation is the technology that appears most beneficial in light of other criteria, such as its chances in the context of industrial policy.
- The analysed **treatment processes** are currently at very different stages in their development: while the methanol-to-gasoline (MtG) technology is already suitable for commercial use, the availability of liquid organic hydrogen carrier (LOHC) coupling and (although this is somewhat uncertain) methanol-to-dimethyl ether is not expected until 2030 and MtK and methanol-to-OME (MtOME) until 2040. It is not possible to make useful comparisons between quantitative indicators for these technologies for the same reasons as those listed above. LOHC coupling and MtOME are considered to have bright prospects as regards industrial policy.

3.2 Supplementary assessment of individual pathways using prospective life cycle assessments

In addition to the criteria-based assessment of PtX technologies, the production of synthetic kerosene via the Fischer-Tropsch and methanol route was analysed as an example based on prospective life cycle assessments (LCA) for 2030 and 2050 and compared with conventional kerosene as a reference fuel. The provided LCA use a well-to-tank approach for production in the MENA region and provision in Germany; the environmental impacts were primarily assessed based on the conventional environmental impact method *ReCiPe 2016*. Background processes for the analysed pathways were adjusted for future developments with the help of the *premise* open source tool by modifying the ecoinvent database (→ *sub-report 2*).

All the analysed synthetic pathways achieved better results than the fossil references for 2050 in the climate change impact category (global warming potential, GWP) if CO_2 from direct air capture (DAC) is used, which is considered to be "climate neutral". The use of atmospheric CO_2 in the PtL routes – despite higher GHG emissions during the production phase – results in significantly lower net impacts for production, including CO_2 emissions from the combustion of the fuel, compared to the reference. Depending on the path, these correspond to a net reduction of 57-84%.

However, disadvantages were found in all of the other categories of impact, particularly as regards land use (ALOP), terrestrial acidification (TAP), eutrophication (FEP) and the cumulative energy demand (CED). This is primarily due to the high volumes of energy required to produce hydrogen and to supply CO_2, but also due the likewise higher raw material requirements for the construction of PtL plants. The type of energy source and heat delivery emerge as the key success factors in terms of environmental impacts, with the use of exclusively renewable sources proving beneficial at sites with high numbers of full load hours.

The results also make it clear that importing hydrogen rather than kerosene results in considerably greater climate impacts. This can be attributed to the high diffusibility of the hydrogen, which leads to significantly higher hydrogen demand and an indirect climate effect due to an increased hydrogen concentration in the atmosphere.

4 Sub-project A.II: Potential and infrastructure analysis for electricity, hydrogen and synfuels

4.1 Determining demand for RE electricity, hydrogen and synfuels

Taking demand in Germany and Europe for RE electricity, hydrogen and synfuels as its basis, this sub-project modelled corresponding supply structures that took the MENA region into account.

Three scenarios for the future development of demand were analysed in order to arrive at robust implications. In keeping with the fact that the modelling of the supply structures only maps production from RE, the sub-project likewise only considered the amount of demand that is to be covered by wind energy (onshore and offshore) and solar energy (PV and CSP technology). While the same assumptions regarding mileage and modal split were applied for the transport sector, the three demand scenarios nonetheless vary with respect to the type of drive technologies and thus the form in which the energy must be supplied. Fig. 4-1 summarises the final energy demand of all sectors for the three demand scenarios in 2050 for Germany. The process for determining these requirements, including scaling German demand to Europe, is outlined in → *sub-report 5*.

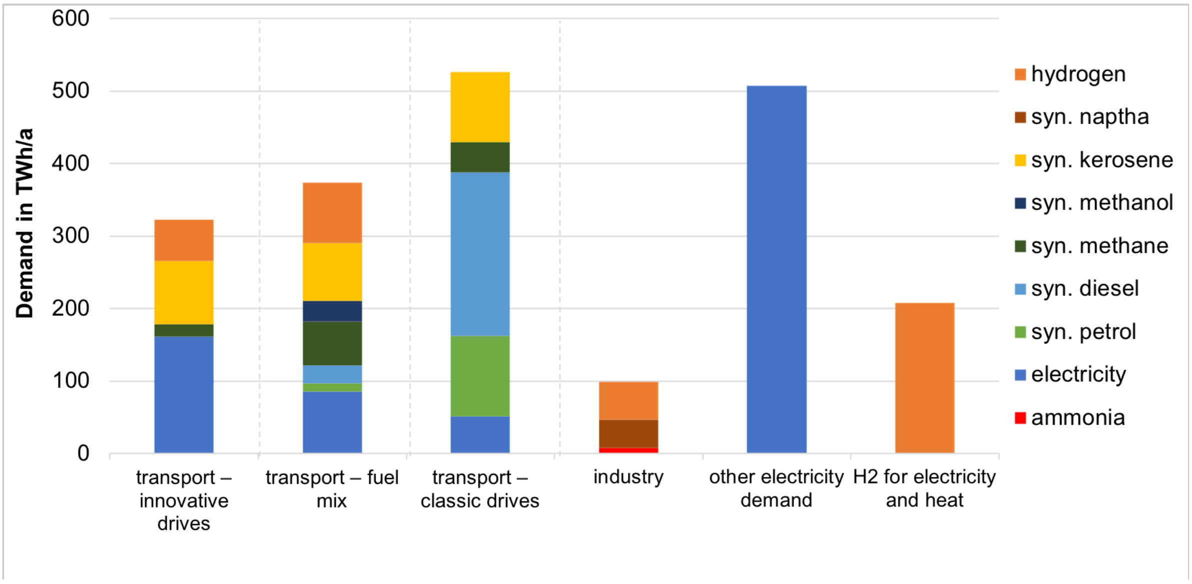


Fig. 4-1 Demand for RE electricity, hydrogen and synfuels in all analysed sectors in Germany in 2050

From today's perspective, the 'fuel mix' (FM) demand scenario represents a plausible option for the development of the transport sector in which various energy sources (electricity, hydrogen, synfuels) are utilised. The 'innovative drives' (EL) and 'classic drives' (SYN) demand scenarios, on the other hand, point to developments with a strong focus on efficiency as well as electric and hydrogen vehicles ('innovative drives') and on synfuels ('classic drives'), which extend the range of potential developments.

Besides the transport sector, assumptions regarding demand in other sectors were also taken into account (synthetic feedstocks from industry, hydrogen demand of the electricity and heat sector and other electricity demand). However, these were not considered in various scenarios but rather consistently incorporated across all scenarios.

4.2 Expansion of the WISEE-ESM-I energy supply model

The supply pathways to meet this demand were modelled and assessed using the WISEE-ESM-I energy supply model created by the Wuppertal Institut. WISEE-ESM-I was developed based on the OSeMOSYS open source framework for energy system planning and expanded here to meet requirements placed on the model by this specific project (Howells et al., 2011; Royal Institute of Technology (KTH) et al., 2022).

WISEE-ESM-I is a linear optimisation model for the long-term planning and assessment of transition pathways with maximum cost-effectiveness for the energy system with the aim of meeting demands on energy sources stemming from external conditions. The production of the required energy sources from inputs (e.g. solar energy) in production facilities via intermediary products (e.g. hydrogen) are explicitly mapped from the perspective of the model. Both the energy supply and energy demand are considered based on temporal and geographical aspects. Operational time periods for mapping short-term fluctuations, e.g. feed-in from RE facilities, are used to this end as well as strategic time periods for modelling long-term developments in the energy system. Storage systems are taken into account in the model in order to compensate for short-term fluctuations in energy supply and demand. In addition, WISEE-ESM-I also maps transport infrastructures to facilitate the exchange of energy sources between the regions in the model.

Key decisions and thus results delivered by the model include the regional and temporal expansion in capacity and the operation of production systems, storage systems and transport infrastructure. The decisions are optimised with respect to minimal overall costs (investment and operating costs) of the energy system. This optimisation process is carried out in keeping with additional relevant conditions such as limits on potential as well as mass and energy balances. A comprehensive description of the model is provided in → *sub-report 4*.

The MENA-Fuels project looked at the time frame from 2030 to 2059, with explicit models being provided at crucial intervals for 2030, 2040 and 2050. The model works with an intrayear resolution in order to accommodate the fact that the availability of renewable energies does not follow a consistent time scale. Each year was reduced to 25 time increments in order to minimise complexity. The time ranges for demand and renewable production were aggregated to this end.

Large sections of Europe and the MENA region are included in the model's spatial frame of reference. A further step to reduce complexity consisted of grouping the required volumes of energy and production potentials of individual countries together to form larger regions called clusters. Germany was depicted as a single region in Europe; the Benelux countries; France, the UK and Ireland, Spain and Portugal were combined to form the *EU_West* cluster in the west. The *EU_North* cluster consists of Norway, Sweden and Denmark in the north. The *EU_East_Southeast* cluster is large in size, including the countries in Eastern Europe extending from Poland to Greece. *EU_South* consists of Italy and Switzerland. The MENA region was broken down into eight regions: the *Middle East* cluster comprises Jordan, Israel, Lebanon, Syria, Iraq and Iran, the *North Arabia* cluster Saudi Arabia, Qatar, Bahrain and Kuwait, the *South Arabia* cluster the United Arab Emirates, Yemen and Oman, the *Maghreb without Tun/Alg* cluster the Maghreb minus Tunisia and Algeria. Algeria, Tunisia, Libya and Egypt were modelled as individual regions.

Production technologies were selected in line with the results from sub-project A.I. Wind onshore and wind offshore, PV and CSP were the modelled electricity production technologies. On the one hand, water can be sourced from seawater via reverse osmosis and vaporisation; on the other, the use of groundwater in Europe was mapped in the model. Water also accrues as a by-product of additional process steps. Alkaline and high-temperature solid oxide electrolysis (SOEL) were modelled as technologies for the delivery of hydrogen. Co-HTE was taken into consideration as a technology for producing synthesis gas. CO_2 is captured from the atmosphere using the low-temperature direct air capture (DAC) technology. Fischer-Tropsch synthesis (high and low-temperature route), methanol synthesis with optional subsequent methanol-to-X process, methanisation and ammonia synthesis were chosen as synthesis technologies. Electric heaters for generating low and high-temperature heat were also depicted as auxiliary technologies in the model. Battery storage units and hydrogen tanks were modelled as storage systems. Gaseous and liquid energy sources are transported via tankers as well as onshore and offshore pipelines[3]; electricity is transported via high-voltage direct current transmission (HVDC) lines. The data on the RE potentials in MENA and Europe differentiated according to their cost-potential category are based on the work carried out in *sub-project B.I.* A comprehensive description of the input data is provided in → *sub-report 6*.

The modelling consisted of analysing a range of scenarios in order to arrive at robust implications. To start with, three scenarios – referred to as basic scenarios below – were analysed that model the energy system from a purely techno-economic perspective without taking into account investment risks in the MENA region. The scenarios vary only with respect to the future development of demand in the transport sector and are named 'fuel mix' (FM), 'innovative drives' (EL) and 'classic drives' (SYN) to match their underlying demand scenarios.

Taking the FM scenario as the basis, an analysis was also conducted of three scenario variants that explicitly map investment risks in the MENA region in the model by depicting the country-specific WACC for production facilities and storage systems (see section 5.1):

- 'FM_risk_bau' (FM_bau) based on WACC_bau (business-as-usual).
- 'FM_risk_positive' (FM_pos) based on WACC_pos.
- 'FM_risk_challenging (FM_neg) based on WACC_neg.

4.3 Results of the basic scenarios without taking investment risks into consideration

The results of the FM, EL and SYN basic scenarios (without taking investment risks into consideration) are presented in Table 4-1 with reference to the European and

[3] Only transport by pipeline is mapped for ammonia.

German import quotas for RE electricity, hydrogen and synfuels. According to this, *electricity* is produced (almost) entirely within Europe and is not imported (or is only imported to a minimal extent). This can be attributed first and foremost to the comparatively high transport costs for electricity, which favours production in close proximity to consumption. Only minimal amounts of electricity are imported in the EL and SYN scenarios, with electricity being imported over a rather short transport distance from Algeria to the *EU_South* cluster. As indicated by the sensitivity analyses in → *sub-report 7,* lower electricity transport costs result in higher quantities of electricity being imported to Europe. However, even if electricity transport costs are reduced by approx. 50 per cent, the volumes of electricity imported from MENA to Europe are still low in comparison to the volumes of synfuels (7 per cent European import quota of electricity in the outcome of the sensitivity calculation).

Table 4-1 Import quotas for Germany and Europe in 2050 for the 'fuel mix,' 'innovative drives' and 'classic drives' scenarios without taking investment risks into consideration

	Innovative drives (EL)	Fuel mix (FM)	Classic drives (SYN)
Germany			
Electricity, domestic	96%	98%	99%
Other energy sources, domestic	0%	1%	3%
Import of electricity	4%	2%	1%
Import of other energy sources	100%	99%	97%
Europe (incl. Germany)			
Electricity, domestic	98%	100%	99.6%
Other energy sources, domestic	39%	18%	19%
Import of electricity	2%	0%	0.4%
Import of other energy sources	61%	82%	81%

On the other hand, imports from the MENA region play a significant role in the supply of *hydrogen and synfuels* to Europe. The FM and SYN scenarios in particular stand out for their high import quotas of 82 per cent and 81 per cent; the import quota in the EL scenario comes in at a lower rate of 61 per cent due to the lower demand for synfuels in this scenario. Comparatively low RE production costs in the MENA region serve as drivers for the import of the energy sources. Generally speaking, the final energy form is imported in all scenarios; conversion steps in the PtX chain are thus largely carried out at the production site.

As per the results of the modelling, all regions within Europe rely on imports from the MENA region. This is particularly the case for Germany as well as Southern and Southeast Europe. Northern and Western Europe meet their own demand at comparatively higher rates. This results in high production volumes in Western Europe in particular due to the high demand in this region.

According to the results of the model, the energy sources are imported, without accounting for the investment risks for all three scenarios, from Algeria, Egypt, the *Maghreb without Tun/Alg* cluster, the *Middle East* cluster, the *South Arabia* cluster and additionally from Libya in the SYN scenario (cf. Fig. 4-2). While the production volumes in the individual MENA regions vary between the three scenarios, the selection of the supply regions in the results of the model is not dependent on how demand develops in the future, or only to a minimal extent. The basic structures for supplying Germany and Europe with RE electricity, hydrogen and synfuels are maintained and are thus robust as regards the future development of demand.

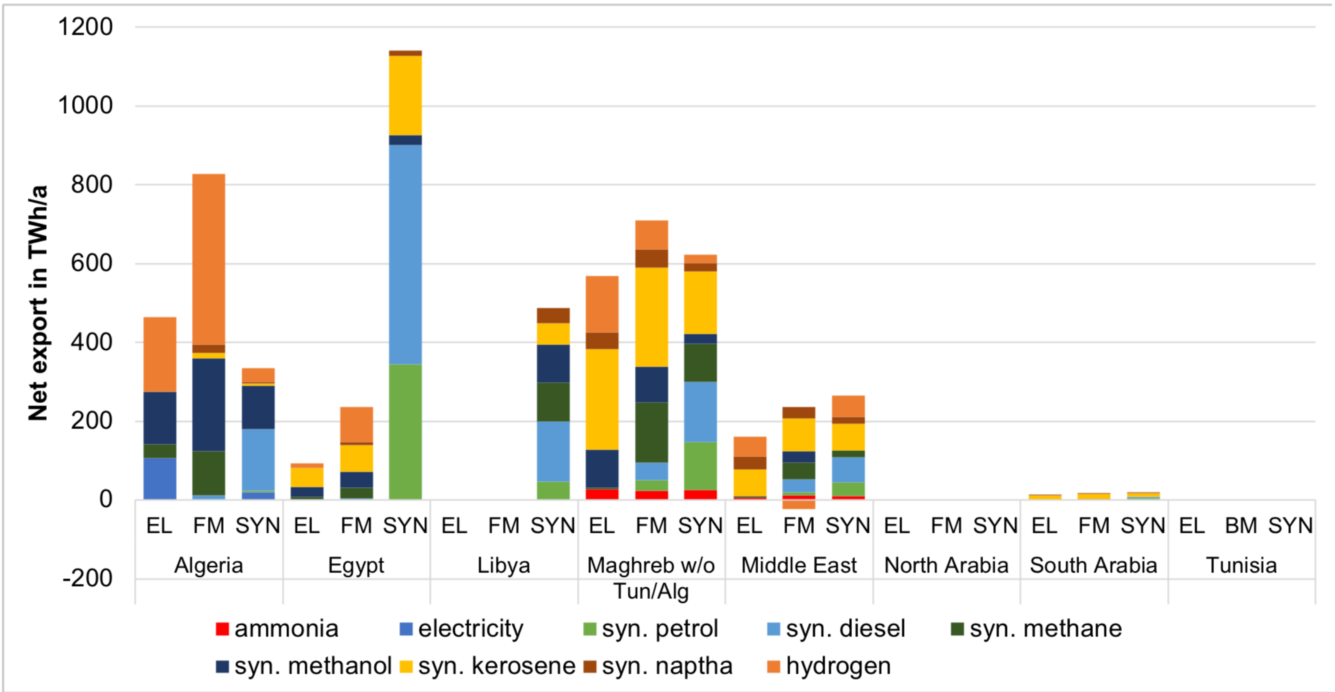


Fig. 4-2 Net export by energy source of the MENA regions and clusters in 2050, 'innovative drives' (EL), 'fuel mix' (FM) and 'classic drives' (SYN) scenarios, without taking investment risks into consideration

According to the results of the modelling, the MENA regions that are attractive as supply regions are generally those that are a *short distance from and thus offer low transport costs* to Europe as well as *advantageous RE feed-in characteristics* (high full load hours for PV systems, along with favourable onshore wind potentials to compensate for solar fluctuations). Nonetheless, these implications should be examined from a critical perspective in light of sensitivity analyses on the amount of transport costs and the intrayear level of temporal detail (→ *sub-project 7*): The sensitivity analyses make it clear that the intrayear RE feed-in time ranges in particular can only be mapped in simplified form due to the low level of temporal detail in the model. Given the fact that many MENA regions offer potential for affordable RE from solar energy with a high number of full load hours, additional MENA regions that were not selected for analysis in the model have the potential to be attractive export regions. In addition, the sensitivity analyses on the transport costs imply that their influence on the selection of the supply regions should not be overestimated (→ *sub-report 7*).

Transport primarily takes place via pipeline for all three scenarios. In terms of transport from MENA to Europe, the preferred routes are the onshore routes via the *Middle East* cluster to Southern Europe and via the *Maghreb without Tun/Alg* cluster to Western Europe based on the assumption that transport costs will be lower using onshore pipeline transport in contrast with offshore. Due to the short transport distance and thus the comparatively low transport costs, synthetic energy sources are also transported via offshore pipelines from Algeria and, in the 'classic drives' scenario, from Libya to Europe via Tunisia as well. According to the results of the modelling, only very low volumes of liquid energy sources (diesel, petrol, naphtha, methanol, kerosene[4]) are transported via tanker. These transports are primarily made across extensive distances from the *South Arabia* cluster, and in the SYN scenario across shorter distances as well.

These results therefore indicate that transport by tanker is economically attractive in the case of long transport distances in particular. At the same time, the results of a sensitivity analysis on lower tanker transport costs (→ *sub-report 7)* also make it clear that when tanker transport costs are lower, a major share of the transport of liquid synfuels is shifted from pipeline to tanker at the specified distances in the EU-MENA region; the transport of gaseous synfuels continues to be carried out via pipelines under the given assumptions. These results make it clear that the extent to which a transport option is advantageous – particularly with respect to the liquid energy sources – largely depends on the internal relationship between the costs for the pipeline or tanker transport for the specified distances in the EUMENA region. However, this internal relationship is also subject to uncertainty due to the uncertainty around the data on transport costs.

As is evident from the analysis of the import quotas above, electricity is not (see FM scenario) imported from the MENA region or is only imported to a very low extent (see EL and SYN scenarios). This is due to its comparatively high transport costs. In keeping with this, the expansion of the electricity grid is limited to inner-European routes as per the results of the modelling and, in the EL and SYN scenarios, to the *EU_South* Algeria cluster route. A factor that should be taken into consideration here is that the model only maps the point-to-point connections between regions and that the results on transport infrastructure therefore likewise only refer to these point-to-point connections. Transport capacities are also needed within the regions but were not depicted within the model.

4 Kerosene is only transported by tanker in the 'fuel mix' (FM)' and 'innovative drives' (EL)' scenarios; in the 'classic drives' (SYN) scenario, this also includes diesel, petrol, methanol and naphtha in addition to kerosene (but in much smaller volumes than kerosene).

4.4 Results of the scenario variants, taking investment risks into consideration

As per the results of the modelling, *taking investment risks into consideration* results in a significant shift in the regional production volumes and thus to a change in the supply structures as well.

One result of this is a *transfer of production to Europe* due to the lower increases in capital costs there, with this aspect being reflected in lower import quotas (cf. Table 4-2). This is particularly pronounced in the case of a challenging risk development situation in the MENA region (FM_neg) for which imports are no longer carried out from the MENA region and the energy sources are produced within Europe in their entirety. This scenario outcome also makes it clear that the European RE potentials are sufficient for supplying Europe with RE electricity, hydrogen and synfuels on a fully self-sufficient basis if demand develops in keeping with the given assumptions on which the FM scenario was based.

Table 4-2 Import quotas for Germany and Europe in 2050 for the 'FM_risk_positive', 'FM_risk_bau', 'FM_risk_challenging' scenario variants, taking investment risks into consideration

	FM (without risk)	FM_risk_ positive	FM_risk_ bau	FM_risk_ challenging
Germany				
Electricity, domestic	98 %	92 %	99 %	99 %
Other energy sources, domestic	1 %	50 %	65 %	72 %
Import of electricity	2 %	8 %	1 %	1 %
Import of other energy sources	99 %	50 %	35 %	28 %
Europe (incl. Germany)				
Electricity, domestic	100 %	100 %	100 %	100 %
Other energy sources, domestic	18 %	66 %	89 %	100 %
Import of electricity	0 %	0 %	0 %	0 %
Import of other energy sources	82 %	34 %	11 %	0 %

On the other hand, accounting for the investment risks in the model results in a *shift in production within the MENA region*. Contrary to the results of the FM basic scenario, production in the FM_pos and FM_bau scenario variants only takes place in the *North Arabia* cluster and, should the risk develop in a positive direction, in the *Maghreb without Tun/Alg* cluster as well. This can be largely attributed to the lower WACC in these regions.

4.5 Sensitivity analyses in relation to the amount of capital costs

Supporting investments on a long-term basis could, however, reduce the risk-related increases in capital costs in individual countries. For this reason, the extent to which lower WACCs would have an impact on the selection of the MENA supply regions was examined based on the example of *Maghreb without Tun/Alg*, Jordan and Oman; the analyses were conducted separately in each case. According to these analyses, a transfer of production would occur at a WACC of up to 5 per cent for Jordan and Oman from the *North Arabia* and *Maghreb without Tun/Alg* clusters, which represent the supply regions in the FM_pos scenario variant. According to this sensitivity analysis, production would take place in *Maghreb without Tun/Alg* at a WACC of up to 7 per cent.

In addition, for all three countries/regions, a share of the production taking place in Europe in the FM_pos variant would be transferred to these countries at a WACC of up to 5 per cent. This is reflected in correspondingly higher import quotas. The extent to which production is transferred is greater the lower the assumed WACC.

According to the results of the modelling, approx. 1,800 to 2,400 TWh/a of synthetic energy sources would be exported from Jordan and around 1,400 to 2,400 TWh/a from Oman to Europe at a WACC of 5 per cent to 1 per cent in Jordan and in Oman in 2050. The export volumes from *Maghreb without Tun/Alg* in 2050 would amount to between 600 and 2,400 TWh/a at local WACC of 7 per cent to 1 per cent. According to the modelling, promoting long-term investments aimed at reducing capital costs can thus turn individual countries and regions into attractive export regions.

In summary, the results make it clear that, when accounting for the investment risks, the level of WACC has a considerable influence on the selection of economically attractive MENA supply regions. Very low WACCs can in fact take precedence over other influencing factors such as the transport distance or the RE feed-in characteristics. However, as demonstrated by the sensitivity analyses, other factors are also relevant in cases where there is little variation in capital costs. While Oman and Jordan are not considered to be export regions at their WACC of 7 per cent, *Maghreb without Tun/Alg* would be economically attractive due to further advantages offered by this location, such as its geographical proximity to Europe, even at a WACC of 7 per cent.

4.6 Critical classification of the research approach

The project developed and applied an energy supply model incorporating a broad range of technologies and provided a differentiated picture of the MENA region. However, the high level of detail in the technological and geographical resolution required reduced complexity at other junctures. One aspect consisted of reducing the number of regions by clustering individual countries to form larger regions. As a result of this clustering process, potential techno-economic advantages enjoyed by individual countries, for example regarding lower RE production costs or a low investment risk, can no longer be explicitly taken into consideration in the model. In addition, the complexity of the model was reduced by using a lower intrayear temporal resolution of 25 time increments per year. Due to this low temporal resolution, the intrayear RE feed-in time ranges in particular could only be mapped in simplified form. As indicated by the sensitivity analyses in → *sub-project 7*, the low temporal resolution can slightly distort the modelling results as regards advantageous MENA supply regions – particularly in light of the circumstance that many MENA countries and regions have favourable solar potential with high numbers of full load hours – as well as the import quotas.

Further limitations of the WISEE-ESM-I energy supply model developed and utilised in this project concern the simplified manner in which the transport of energy sources is depicted in particular. For one, no load flow calculation was carried out for electricity; in addition, it was assumed that there would be a ‘copperplate’, or fully connected grid, within the modelled regions; i.e., that energy sources can be transported without restrictions and without losses within a region. Transport was modelled using point-to-point connections between the individual regions, which means that plans for infrastructure cannot be determined based on the results of the modelling. In addition, existing transport infrastructure was not explicitly represented in the model. Rather, an ex-post comparison of the development and capacity of existing infrastructure was carried out with the results of the modelling. Moreover, economies of scale for pipelines were not taken into account in the model.

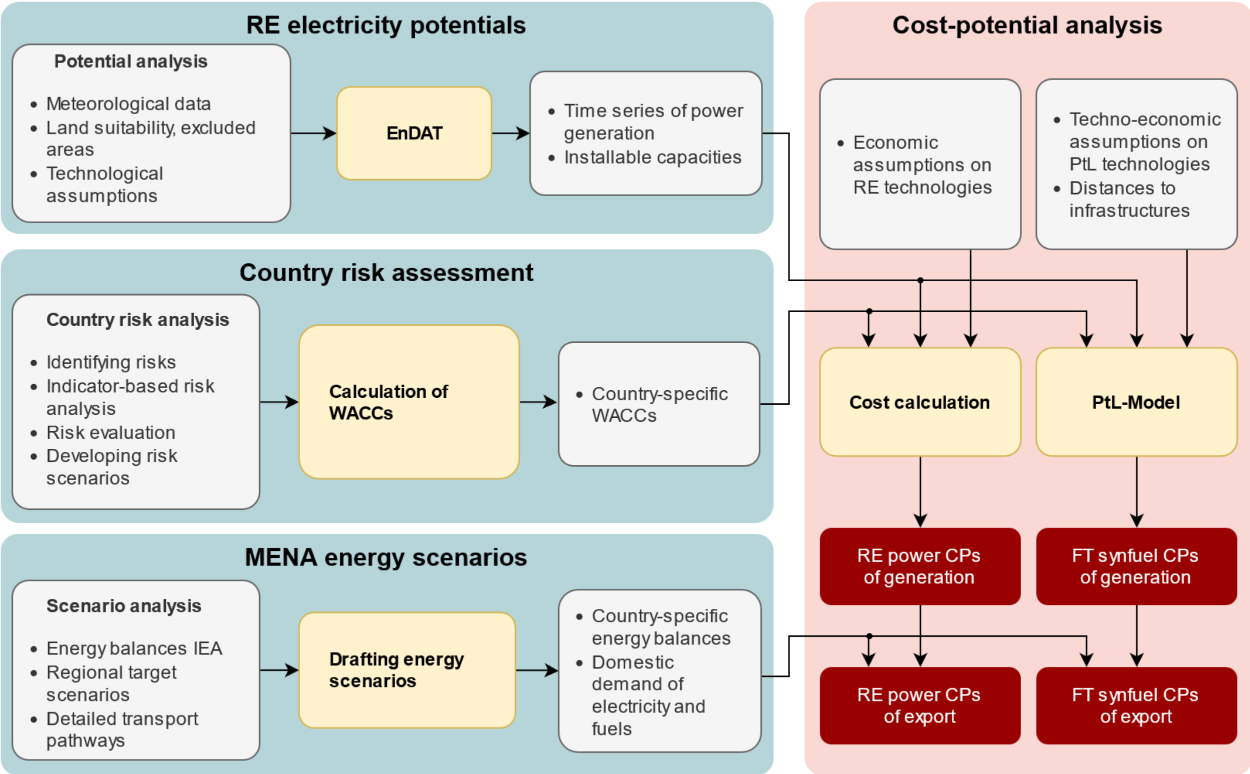
Besides this, existing investment measures in production facilities and transport infrastructure on the part of industry as well as regional characteristics could only be taken into consideration to a limited extent in the energy supply model. WISEE-ESM-I is also a deterministic model, which means that uncertainties in the parameters are not explicitly represented in the model. In addition to this, the model only assesses potential supply structures in light of the specified system costs; for this reason, aspects that cannot be determined based on the results include prices along with configurations that are optimal in terms of society, the overall economy or the environment.

5 Sub-project B.I: Analysis of export potentials in the MENA countries

Sub-project B.I aimed to identify the potential for renewable energies or synthetic fuels that could be available in the MENA countries over the long term and at what export costs. This included considering both the potential long-term domestic demand in the countries as well as the influence that country-specific risks have on the costs. The work steps in sub-project B.I covered the following aspects:

- **Country risk assessment and determining the costs of risks:** Assessment of the country-specific risks for the development of a renewable energy sector and a synthetic fuel sector as well as translating these country risks into increases in capital costs for the MENA countries (→ *sub-report 8)*.
- **Modelling energy scenarios for the MENA countries:** Determining long-term demand for renewable electricity and synthetic fuels in the MENA countries *(→ sub-report 9)*
- **Cost potential analyses:** Determining the long-term potentials and costs of electricity, hydrogen and synthetic fuels in the MENA countries *(→ sub-report 10)*
- **Short country studies:** Conducting short studies in Jordan, Morocco and Oman on the general conditions for exporting synthetic fuels (→ *sub-report 11)*

The key results are risk-assessed cost potentials for renewable energies (PV, CSP and onshore wind) and synthetic fuels (Fischer-Tropsch (FT) route) for 17 MENA countries and regions. Fig. 5-1 provides an overview of the key work steps, input data and interim results for calculating the cost potentials. The general infrastructure and the industrial frame conditions at the local level in the MENA countries were exemplarily analysed using three short studies in Jordan, Morocco and Oman in order to reflect on the theoretical insights and review the assumptions that had been made.



RE: Renewable Energy, **EnDAT**: Energy-Data-Analysis-Tool, **FT**: Fischer-Tropsch, **IEA**: International Energy Agency, **CPs**: Cost-Potentials, **MENA**: Middle East and North Africa, **PtL**: Power-to-Liquid, **WACC**: Weighted Average Cost of Capital

Fig. 5-1 Overview of key work steps, input data and interim results for calculating the cost potentials

Source: DLR and Wuppertal Institut

5.1 Country risk assessment and risk costs

Country risk assessment

The question of which countries in the MENA region will (continue to) develop a renewable energy sector as well as a synthetic fuel sector in an advantageous manner is closely linked to the question of the risk involved in investments and business activities in these sectors in the individual countries. This applies to both developments to meet the countries' domestic demand as well as to the expansion of export capacities for synthetic fuels and their precursors, including hydrogen. A comparative analysis of the countries' risk levels was conducted in the present study for all the MENA countries under consideration in order to assess the risks for the development of an export sector for RE and synthetic fuels produced on this basis. The country risk assessment consisted of the three steps, 'risk identification', 'risk analysis' and 'risk evaluation', and is described in detail in → *sub-report 8*.

1 | The first step identified eleven risks based on a detailed literature analysis, a top-down impact analysis and a register of risks (Fig. 5-2).

2 | An indicator-based analytical framework was developed in order to examine and assess these risks. A total of over 100 quantitative as well as qualitative indicators were analysed. A number of synthesis steps were then used to compile the

individual assessments of the indicators, creating a qualitative assessment at the risk level.

3 | The risk analysis including the assessment of indicators and qualitative synthesis provided the input for risk evaluation, which was performed in the subsequent step. The evaluation was carried out based on two dimensions: *probability* and *impact*. Both dimensions were recorded on a five-step scale in each case and multiplied in the form of a matrix to yield a risk level. The individual risk levels were combined to produce an overall level of risk for each of the respective countries so that the overall risk could be compared between the countries.

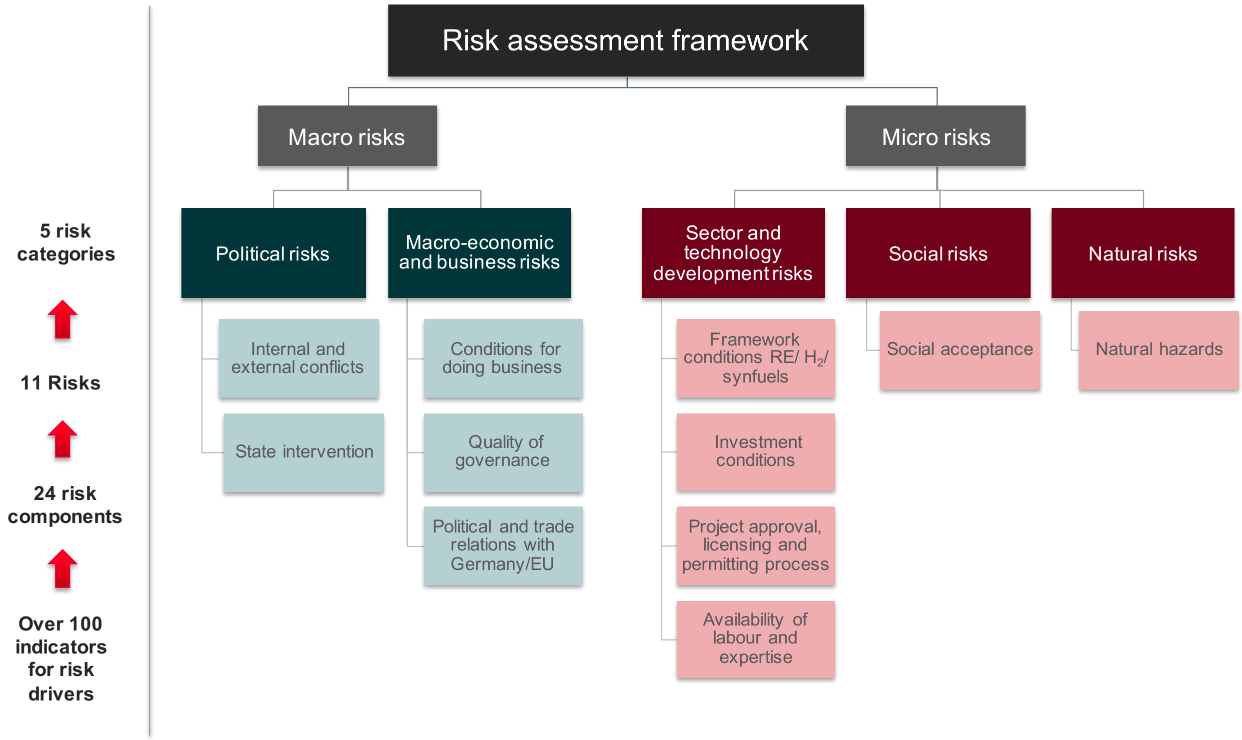


Fig. 5-2 Overview of the analysed country risks

Source: Wuppertal Institut

A risk assessment typically reflects the estimated risk at the present point in time for the near future. However, the goal of the study was to estimate and consider the risks for the longer-term development of the sectors in particular. At the same time, making statements regarding the future is difficult given the complexity and wide range of potential events that could occur at the international, national and regional levels and their causal relationships. This is particularly true in an often turbulent region such as North Africa and the Middle East. In order to account for these uncertainties, two additional contrasting scenario narratives describing the scope of potential events that could occur were developed in addition to the present-day risk assessment (referred to as the *Risk_bau* risk scenario).

The first risk scenario describes a *positive development* in which the risks lessen and which is thus beneficial for the development of renewable energies and the production of synthetic fuels (*Risk_pos*). The second scenario, on the other hand, highlights challenging developments that have the potential to increase risks in both sectors (*Risk_neg*). These narratives were applied to the respective individual situation in the 17 countries analysed, and the risk was assessed accordingly. Fig. 5-3 shows the result of this assessment in the form of the overall level of risk in a country based on the example of the synthetic fuel sector and for the positive scenario in which a reduction of the risks is assumed.

Fig. 5-3 National levels of risk for the synthetic fuel sector for the Risk_pos risk scenario

Source: Wuppertal Institut

Country-specific increases in capital costs

Risks must be mapped in the form of costs so the identified national risks can be incorporated into the cost-potential analysis. To this end, an approach was developed in the project that could be used to translate the previously established risk scenarios into country-specific increases in capital costs. This approach is based on the assumption that a higher level of risk requires higher returns on capital, which is reflected in higher capital costs. Put in simple terms, the weighted average capital costs (WACC) consist of three components: interest on secure investments, country risk premium and technology risk premium. Based on the premise that the risks are (completely) inherent to technologies and the associated increases in capital costs are identical in all countries, the variation in capital costs can be defined for debt and equity capital between countries as the country-specific risk costs.

The risk assessments were transferred into country-specific increases in capital costs over the course of three subsequent steps:

1 | In the first step, the current debt and equity capital costs were determined for each country.

2 | The second step consisted of quantifying the amounts of the previously established risks from the Risk_bau scenario to the current financing costs. The so-called 'financing cost waterfall' method defined by Waissbein et al. (2013) was used for this purpose.

3 | In the third step, the increases in capital costs were calculated for individual countries based on the two risk scenarios. To this end, the risk assessments for the positive (Risk_pos) and challenging (Risk_neg) scenarios were considered in relation to the risk assessment in the business-as-usual scenario (Risk_bau) and the previously established current capital costs for the respective country.

This resulted in country-specific increases in capital costs for the analysed MENA countries, which, in turn, constitute three WACC scenarios (Fig. 5-4).

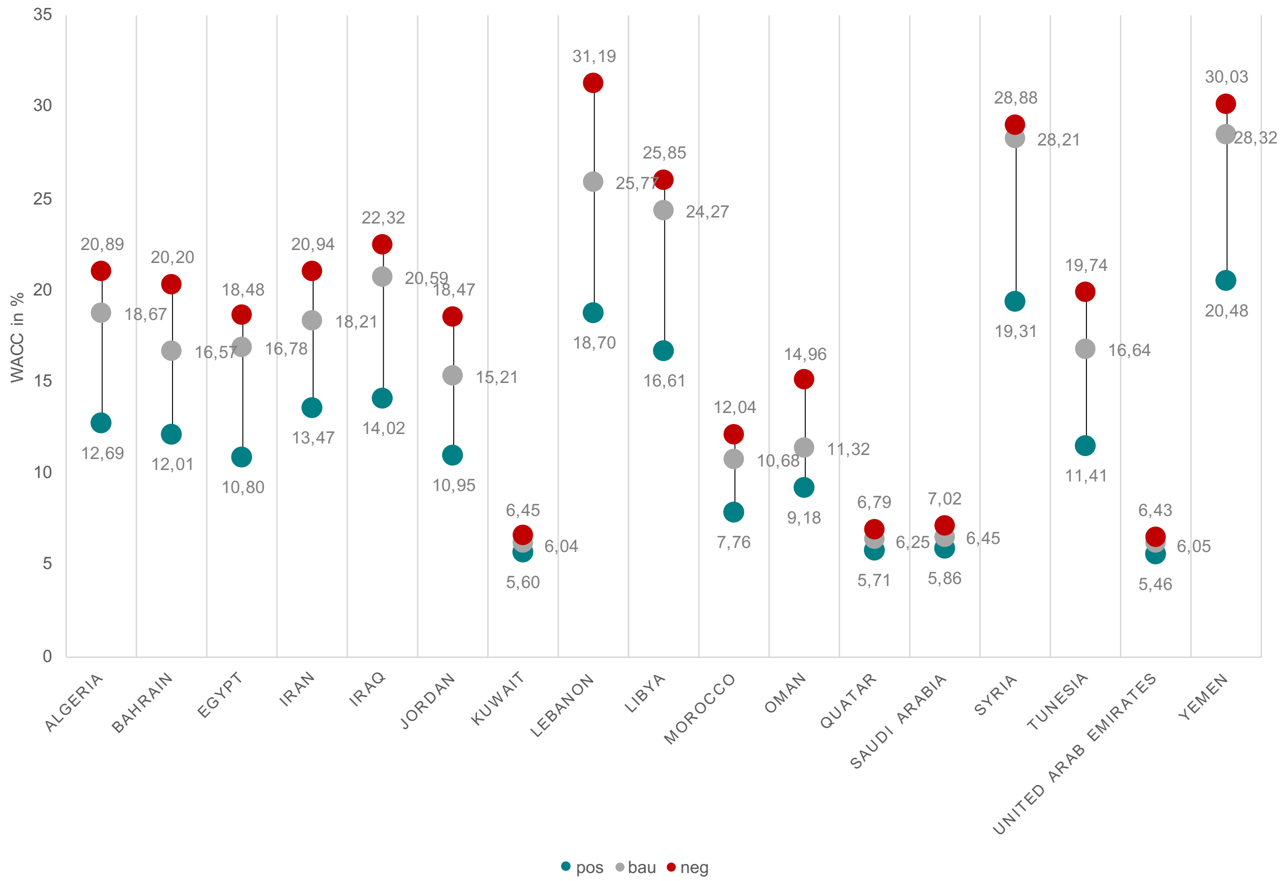


Fig. 5-4 WACC scenarios (adjusted for inflation, before tax)

Source: Wuppertal Institut

The WACC_bau scenario is based on the Risk_bau risk scenario, the WACC_pos scenario on the Risk_pos risk scenario and the WACC_neg scenario on the Risk_neg risk scenario.

The approach applied here makes it possible to quantify the country risks, which are often originally of a qualitative nature, in the form of potential future increases in capital costs. However, basing the quantification on current capital costs results in a deviation between the range of the increases in capital costs for the various scenarios and the range of the risk scenarios in some cases. This is particularly true for countries that have particularly low capital costs at present. Only more minimal changes in capital costs are evident here in relation to the FM_bau scenario, even for the challenging FM_neg scenario, while the risk scenarios exhibit higher levels of risk to some extent. The actual development of the WACC thus has the potential to deviate from the values modelled here and span a wider range in the individual countries. It is also important to note that the information provided here represents an estimate for the overall development of the sectors in a country. Individual projects may exhibit individual capital cost structures that deviate from this overall view. In addition, state or multilateral financing instruments can play a role in making capital available at lower costs than those calculated here.

5.2 Energy scenarios for the MENA countries

Modelling demand and developing scenarios

The assessment of the potential energy and fuel demand in future was carried out separately for the two regions North Africa and Middle East as well as the 17 individual countries. A total of four scenario variants were considered, with these variants pursuing different narratives for the energy sector and spanning the scope of possibilities for the development of domestic demand. This method is based on bottom-up scenario modelling using an accounting framework and calibration of the model with country-specific statistical data (particularly IEA, 2017a) as well as available regional scenarios that are suitable for the narratives. The results of the process of identifying power generation potentials and installable capacities (see section 5.3) form the essential basis for presenting examples of future power generation structures.

The developed scenarios do not claim to deliver a differentiated analysis and assessment for the socio-technical transitions in the countries. A focus was placed on developing energy balances for the countries under the assumption that production structures would be diversified and system costs would not be optimised. More in-depth analyses of the infrastructure requirements (storage units, grids and other flexible aspects) based on the required load balancing in the power system as well as the exchange and trade of energy between the countries could not be carried out in the course of the project. Required imports from neighbouring countries are not explicitly indicated; hence, the results on the production side represent theoretical values for an exclusively domestic supply. Further information on the development of scenarios can be found in → *sub-project 9*.

The following scenario variants were considered:

- *Reference scenario (REF):* follows the Current Policies Scenario from the IEA's World Energy Outlook with the assumption that current policies will be continued without potential policy initiatives in future as a reference value for the maximum demand for fossil energy sources and maximum carbon emissions. Does not include the effects of Covid-19 but incorporates current planning in the electricity sector.
- *Alternative moderate RE strategy (ALT):* Moderate efficiency and RE expansion strategies. Starts with currently known MENA country goals for RE expansion,

supplemented by a regional pathway that is delayed by around 10 years at a minimum goal of 80 per cent GHG reduction by 2050 (compared with 1990). Positioned between REF and ADV as regards the development of efficiency and degree of electrification.

- *100% RE scenario (ADV):* Ambitious scenario with 100 per cent RE and zero carbon emissions by 2050. Based on the global 2°C scenario of (Teske et al., 2019). Remaining demand for gas as well as combustibles and fuels are completely substituted by synthetic energy sources, complementing extensive electrification and direct use of hydrogen. No biofuels in transport as per the IEA SDS scenarios from the World Energy Outlook (IEA, 2017b). Includes PtL production as a replacement for bunker fuels (maritime transport and international aviation) as well as for fossil non-energy consumption in the industry.
- *ALT variant with 100% synthetic fuels in 2050 (ALT2):* Alternative scenario with moderate efficiency and RE expansion strategies in line with the ALT scenario, coupled with the assumption that the remaining fossil fuels would be fully replaced by 2050 in order to reach the goal of 100 per cent RE. Lower direct use of renewable electricity and renewable heat and less ambitious efficiency trends. This variant thus provides a maximised estimate of the potential domestic demand in the countries.

Results of the scenarios

Fig. 5-5 shows the overall energy demand for all types of energies and modes of transport resulting from the bottom-up projection of the transport sector as a sum of all 17 MENA countries and regions. While the *reference scenario* yields a very steep rise in consumption between 2015 and 2050 by the factor of 2.4, the rise in the *moderate scenario* only amounts to a factor of 1.6. In the *ambitious scenario*, ADV, demand declines slightly over the long term in comparison with current levels, which can be attributed to the sharp decline in specific consumption, extensive electrification and consistent shift over to the most efficient modes of transport.

A potential demand for PtL is only assumed in the two 100 per cent RE scenarios. In the case of the ADV scenario, this figure sees an overall increase for all MENA countries from 143 PJ in 2030 to approx. 2,470 PJ in 2040 and approx. 5,360 PJ in 2050. In scenario ALT2, which is moderate as regards the reduction in consumption, the domestic demand is consistently higher when making the same assumptions regarding the timing of the implementation of PtL. In this case, demand increases from 194 PJ in 2030 to approx. 4,380 PJ in 2040 and approx. 13,100 PJ in 2050.

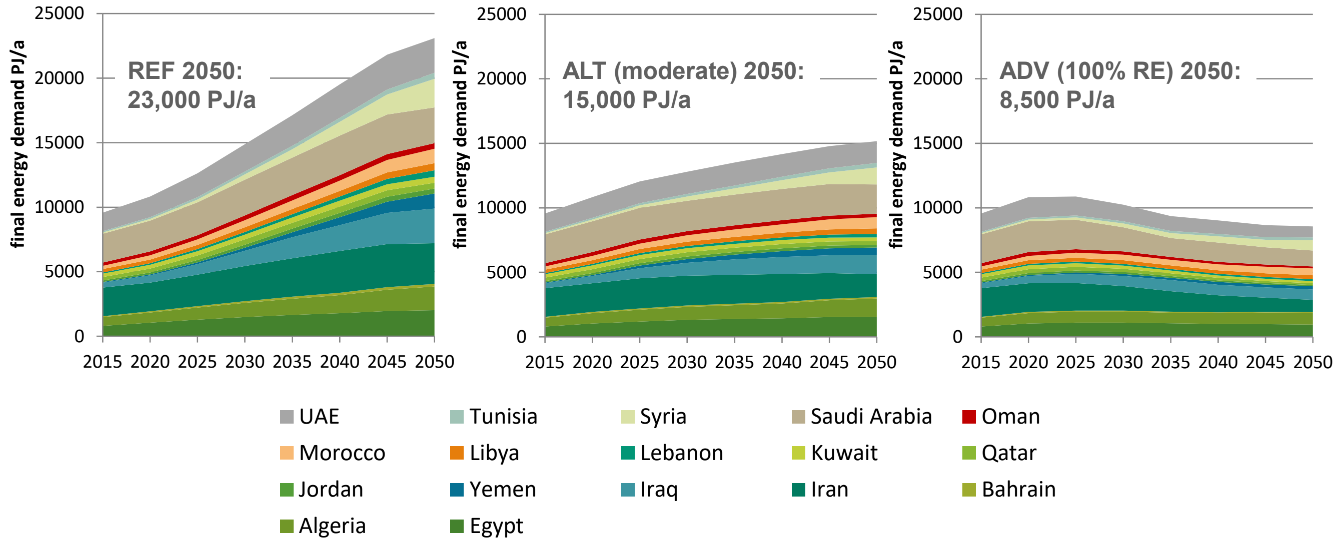


Fig. 5-5 Development of final energy consumption in transport for all analysed MENA countries in the REF, ALT and ADV scenarios

Source: DLR

The overall demand for renewable electricity was estimated for each country based on the total demand for electricity, both from the end-use sectors and for the production of hydrogen and synthetic fuels. Fig. 5-6 shows the corresponding development of electricity generation from wind power (onshore and offshore) and solar energy (PV and CSP) in the two 100 per cent RE scenarios in the form of the annual volumes generated and the installed capacities required for this purpose. Contributions from other renewable energies (biomass, geothermal, ocean energy) and hydrogen reconversion are not shown.

The results point to an increase in the installed capacities for wind and solar power in the ADV scenario to nearly 4,500 GW with electricity production amounting to 9,700 TWh in 2050 for the MENA countries analysed. Both the capacities and the annual volumes of electricity required in 2050 increase by a factor of 2 in the ALT2 scenario. Even though the requirements placed on the power system in the two 100 per cent scenarios are enormous and exceed the current goals of the MENA countries by multiple orders of magnitude in most cases, the technical potentials in countries with large areas of potentially available land shown in section 5.3 are utilised to a minimal extent. Taking the sum of all MENA countries, the technical wind and solar potentials in the two RE scenarios are utilised at a rate of 1.5 per cent and 3 per cent, without future competition for space being taken into consideration. Further figures from the results can be found in → *sub-project 9*.

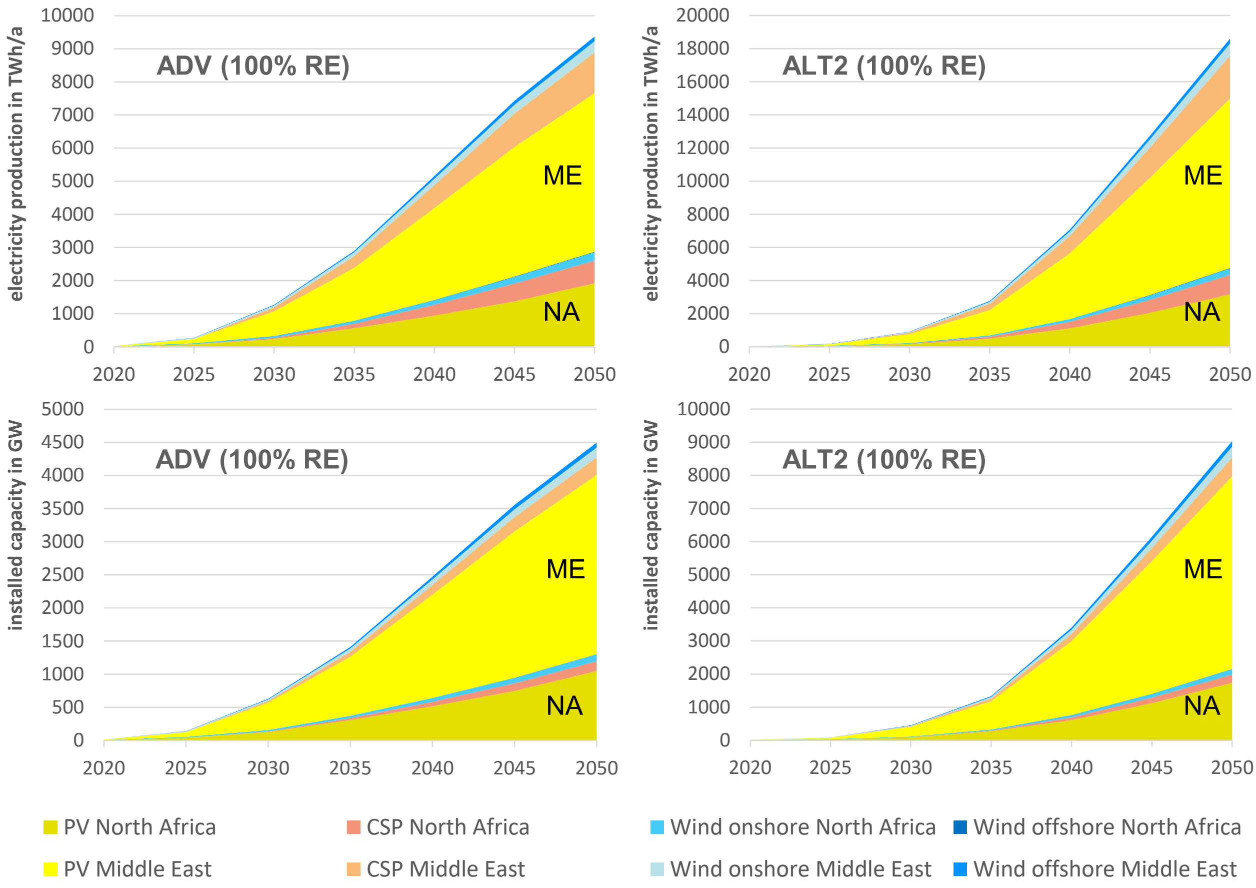


Fig. 5-6 Example for the development of annual volumes and installed capacities for electricity production from sun and wind in the ADV and ALT2 scenarios

Source: DLR

5.3 Analysis of technical aspects and cost-potential in relation to risks

The cost-potential analysis (CPA) for RE electricity and Fischer-Tropsch (FT) fuels consists of identifying technically feasible production potentials as well as export potentials and the accompanying production costs for the respective target product, also known as cost potentials (CPs). This is intended to support the identification of suitable regions for the production of RE electricity and fuels (see also → *sub-report 10*).

The CPA for RE electricity and FT fuels was carried out using various methods. The CPA for RE electricity was conducted by means of a simple calculation of costs, whereas the CPA for FT fuels was based on a modelling of the PtL route. Both methods were used to firstly determine cost potentials involved in production with the help of data on potentials and the country risk assessment. The domestic demand determined in the energy scenarios was then deducted from the most favourable production potential in order to find the cost potentials in terms of export (export potential). The figures from the ALT2 scenario were used to arrive at a high estimate for the domestic demand effect (see section 5.2).

This approach was used to determine CPs for various scenarios. The dimensions of the scenario's scope consisted of

- the type of RE technology: PV, CSP, wind power,
- the time frame: 2030, 2040, 2050 and
- trends in country risks in the form of country-specific WACC as per 5.1: WACC_ref (6 per cent for all countries), WACC_bau, WACC_pos, WACC_neg (respective individual WACC for each country)

Determining RE electricity potentials

The process of determining RE electricity potential consists of calculating installable capacities for PV, CSP and wind energy systems as well as their hourly power generation and annual production potentials and costs. This was carried out in the DLR's energy data analysis tool (EnDAT) using the four work steps described below: The approach was developed for Europe by Scholz (Scholz, 2012) and expanded to a global scale by Stetter (Stetter, 2014).

1 | **Analysis of the resources:** Meteorological data (solar radiation, wind speeds) for the representative meteorological year 2002 were pre-processed for the modelling at a temporal and spatial resolution.

2 | **Analysis of the available land area:** Land exclusion criteria, land cover data and land use factors were considered to this end. The land area analysis resulted in installable capacities for RE systems.

3 | **Power plant model:** Power production time ranges at an hourly resolution were generated based on technological assumptions.

4 | **Economic viewpoint:** Annual power production costs were calculated using the installable capacities and with the help of assumptions regarding investment and operating costs. We were able to determine average production costs for various potential classes using the costs and the associated potentials. Based on this, it was subsequently possible to carry out a spatial aggregation for regional time ranges and cost potentials.

The steps described above were carried out in a defined spatial raster cell resolution of 0.045° (approx. 5 km) worldwide for 88 countries. The data were then aggregated for defined regions. Aggregation took various forms depending on the application (energy system, energy scenario, market, cost potential analysis). In order to perform the further CPA, the data was aggregated at a more coarse resolution of 0.45° (approx. 50 km) in the 17 MENA countries.

Cost-potential analysis for RE electricity

Reference CPs were formed on the basis of the annual production potentials determined in the previous section and the associated production costs. These were adjusted for the various WACC scenarios (WACC_bau, WACC_pos, WACC_neg) by means of a scaling factor that was calculated using the country-specific WACCs, among other aspects.

Cost-potential analysis for FT fuels

The generation costs for FT fuels were determined based on a modelling of a PtL route. The techno-economic PtL model outlined production systems that were optimised in terms of costs, in line with relevant constraints such as mass and energy balances. It was assumed that the production facilities would be stand-alone systems without a connection to the grid. The input for the model consisted of the time range of the hourly electricity generation, techno-economic assumptions regarding system components, distance maps for infrastructure and country and technology-specific WACCs.

The PtL route comprised a PtL system and the necessary provision of electricity. This provision of electricity consisted of an RE power plant, an energy storage unit (battery or thermal energy storage) and power transmission. The PtL system consisted of a PEM electrolysis, a hydrogen storage unit and FT synthesis. In terms of the PtL process, the electricity and water requirements of the electrolyser and the carbon dioxide (CO_2) requirement were taken into account. The electricity and water (H_2O) required for electrolysis as well as carbon dioxide (CO_2) for the RWGS reactor integrated into the FT synthesis process here were mapped for the PtL process. Given the better connections to infrastructure, it was assumed that the PtL system would be located near a harbour and that the RE electricity would be sourced from solar or wind power plants from the respective local 50-km raster cell under consideration. Water is obtained from a seawater reverse osmosis system and CO_2 from cement plants located near the coast or, over the long term, from cost-effective DAC plants.

The volume of fuel that could be produced was projected with the respective maximum of installable capacity of the RE plants at the local site, resulting in the technically feasible production potential. In the final step, the domestic demands of the MENA countries (see section 5.2) were deducted from the most advantageous production potentials in each case, thus yielding the export potentials or CPs in terms of export.

Fig. 5-7 shows the export potentials for 2050 as an example for FT fuel, using a consistent reference WACC of 6 per cent in all countries. This indicates that sufficiently high export potentials with low generation costs exist for Germany and Europe (see also section 4.1) in comparison with fuel demand.

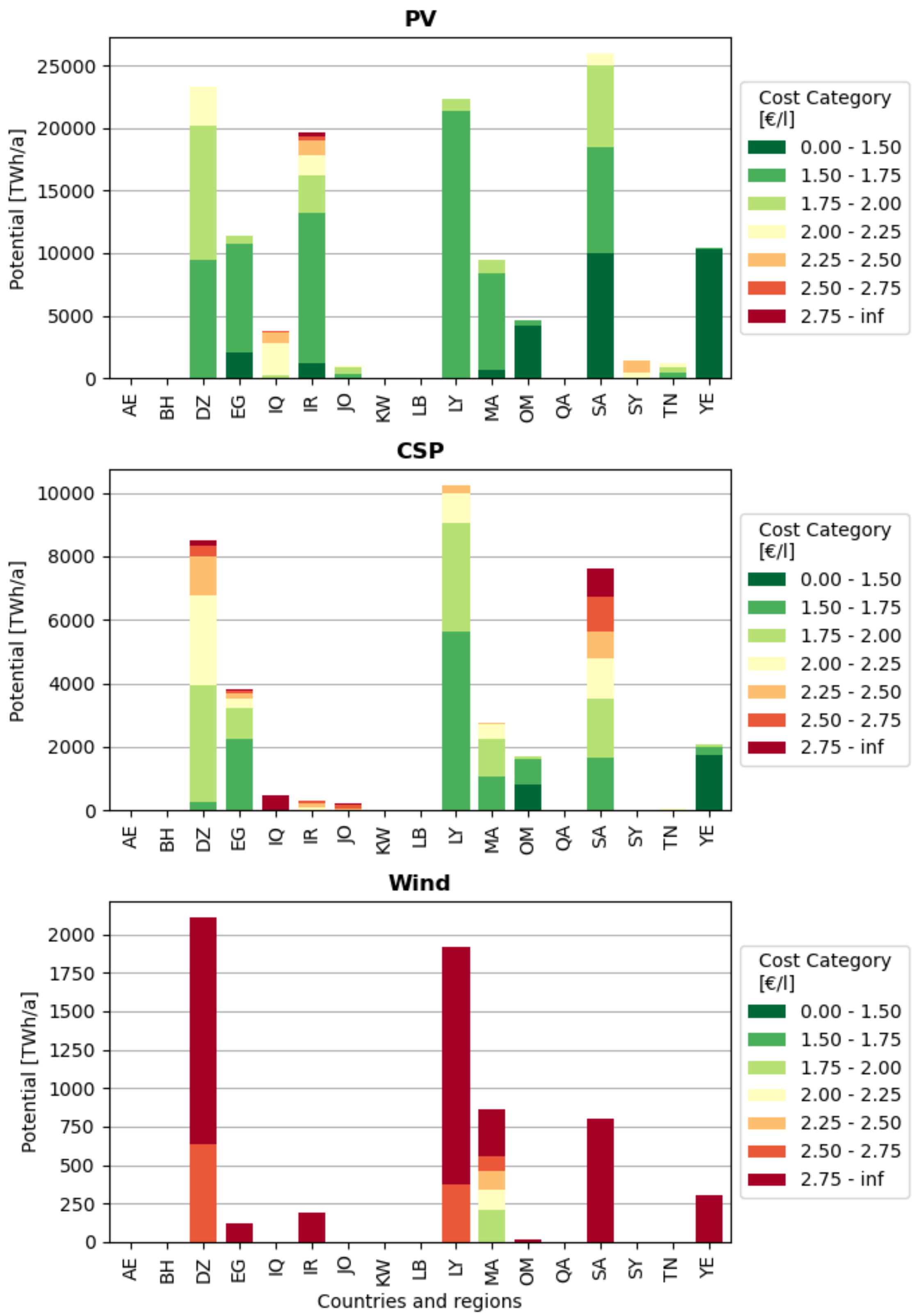


Fig. 5-7 Export potentials by country for Fischer-Tropsch fuel with photovoltaics, CSP and wind in 2050 at a reference WACC of 6 per cent

Fig. 5-8 shows the local generation costs for the example of FT fuel with PV in 2050 at a reference WACC of 6 per cent.

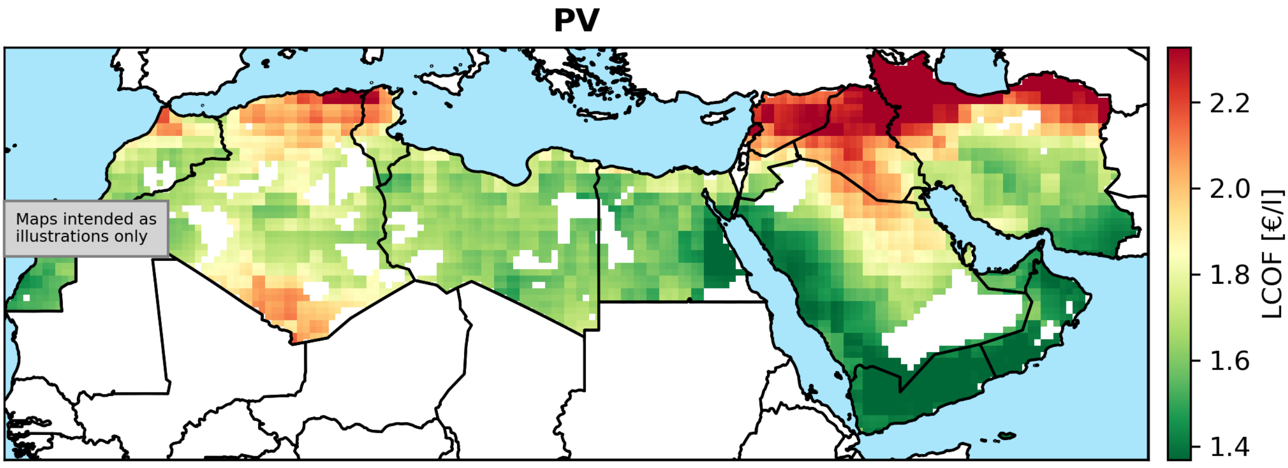


Fig. 5-8: Levelised cost of fuels (LCOF) for Fischer-Tropsch fuel based on photovoltaics in 2050 at a reference WACC of 6 per cent

5.4 Synthesis of the short country studies

Short country studies in Jordan, Morocco and Oman were carried out by external contractors in order to assess the theoretical insights under specific general conditions in individual MENA countries. Specifically, the general conditions for the development of an export sector for hydrogen and synthetic downstream products were analysed with respect to the infrastructural and industrial prerequisites, and relevant stakeholders and their interests were identified (see also → *sub-report 11)*.

The three countries for the short studies were selected based on the results of the analyses carried out in the course of the MENA-Fuels project, the recommendations from the two committees and their feasibility in the context of the general financial and timing conditions specified for the project. In addition, the short studies needed to take into account countries from both regions, North Africa and the Middle East, and provide for a measure of diversity with regard to the country's current role in the global energy system as an oil or gas exporter or as an energy importer.

The **short study on Morocco** shows that the country has high ambitions as a global leader in the expansion of renewable energies, including with regard to the development of a hydrogen economy. Morocco aims to become the global market leader in the production of green hydrogen, and this is backed up by strong political support for the development of an export sector for green hydrogen and other synthetic energy sources. Morocco is currently developing a hydrogen road map that also quantifies its targets for export volumes. In addition, the country has already concluded a number of partnership agreements with European countries that involve green hydrogen. Initial pilot plants are in the planning stages, and a green hydrogen cluster – GreenH_2 Maroc – is already focusing on the development and industrialisation of green hydrogen. There is a great deal of interest in Morocco as an exporter of green synthetic fuels on the part of the industrial sector in Germany and Europe. As regards infrastructure conditions, Morocco has a good starting basis with a relatively well developed power grid, an existing gas pipeline to Spain, existing salt caverns that can be used for the storage of hydrogen and a well-developed harbour infrastructure. In terms of industry, the country is home to a significant chemical industry, particularly in the fertiliser segment; on the other hand, its activities in the petrochemical field and the gas industry are limited.

The **short study on Oman** demonstrates that the country is also a very attractive location as regards the development of green hydrogen projects for subsequent export. Hydrogen appears to have gained a reputation as a potential new economic sector in the country, where the economy has been largely reliant on exports of oil thus far. In this same vein, a hydrogen strategy envisaging high export volumes is currently under development. The conditions for this appear to be favourable, as the country is home to sites that are close to the coast and have renewable energy profiles that create scope for a high number of full load hours. At the same time, Oman occupies a geographically favourable location between Europe and Asia, is politically stable and offers a very good business environment. Various projects on green hydrogen and synthetic fuels have already been announced, including a large-scale, 25-GW project. A national hydrogen alliance called Hy-Fly was set up with the goal of accelerating the development and use of clean hydrogen and establishing a mature hydrogen economy by 2040. In addition to very high expansion rates for renewable energies, corresponding expansion of the power grid is a further infrastructural condition required for the development of a hydrogen export sector. Transport and water desalination capacities also need to be expanded. In terms of its industrial sector, Oman has a relevant chemical industry as well as extensive experience in the extraction and further processing of oil and gas, which can be used for the development of synthetic fuel production.

The **short study on Jordan** shows that the country is in a good starting position as a pioneer in the development of renewable energies in the MENA region. However, its developments in the area of green hydrogen and synthetic fuels have yet to progress to the point of those in Morocco or Oman. Due to excess capacities in electricity generation, Jordan has a great deal of interest in storing electricity and exporting surpluses. In addition to direct exports of electricity, the production of green synthetic energy sources for export has the potential to be an interesting strategy for Jordan. As regards concrete projects, initial discussions have been carried out so far between an Australian company and the Jordanian government regarding a feasibility study on the production of green hydrogen. In terms of infrastructure, the power grid in Jordan needs to be expanded to accommodate the development of a green hydrogen sector; this would facilitate the transport of RE electricity from the sites with the highest yields in the east, central region and south of the country to potential production sites in Amman, Maan or Aqaba. At the same time, the supply of water via desalination will also be a critical factor for the production of green hydrogen given that there is a lack of desalination capacities thus far. On the other hand, Jordan has experience in the storage of natural gas in salt caverns in Amman and Aqaba, where potential hubs for green hydrogen could be developed. In addition, Jordan is home to a relevant chemical industry that produces fertilisers based on potassium and phosphate.

When looking at all the short studies, the **conclusion** can be drawn that (initial) activities relating to green hydrogen and synthetic fuels are already underway in all three countries and that strategic export goals are currently being set out in Morocco and Oman. A range of large-scale projects for producing hydrogen and synthetic fuels for export have already been announced in Oman and Morocco in particular. The expansion volumes required in the area of renewable energies and the transmission and transport structure are correspondingly high, particularly when the additionality of the production of renewable energies has to be ensured. Expansion rates up to this point must be exceeded many times over in order to achieve the envisioned target capacities. There are significant challenges here in relation to capacity and resource management that have the potential to result in bottlenecks in the implementation of the plans. In addition, the options for sites in all three countries have to be examined in greater detail; i.e. as to whether the production of hydrogen and synthetic fuels should be carried out at the sites for renewable energies or rather at harbour locations for direct export, as this has a significant impact on the required transport infrastructure.

6 Sub-project B.II: Future markets, trade products and value chains

The goal of this sub-project was to analyse economic issues in conjunction with the cost potentials determined in sub-project B.I and the scenarios building on this as regards the import of synthetic fuels to Germany in sub-project A.II. The content of this sub-project covered the following work steps:

- Future markets and trade products (→ *sub-report 12*)
- Overall economic, socio-economic and environment-related distribution effects (→ *sub-report 13*)

Each of these steps is set out in detail in the following.

6.1 Development of a global trade model for reviewing correlations with the EUMENA region

By replicating a global trade system with green hydrogen and synfuels, the aim was to provide an indication as to whether the relationships between countries in the MENA region and Europe – specifically Germany – that were identified in sub-project A.II would continue to be valid in a global market or whether there is the potential for competitive relationships. Given this, supply and demand in other countries outside the EUMENA region were identified and a potential exchange of goods with these countries was reviewed.

Developing a trade model

A trade model was developed to this end, taking into account two main premises: (1) There is a global competitive market that makes it possible in principle to offer all production potentials to all sources of demand, and (2) trade is primarily carried out between those partners where the highest margin per trade unit is expected. Restricting factors in this context are country-specific interest rate levels for investments in the form of weighted average capital costs (WACC), transport costs, trade restrictions (embargoes) and customs duties. Given that, during the project, there was as of yet no definition for green hydrogen with regard to the power quality (e.g., recognition of green electricity certificate trading, long-term electricity supply contracts with renewable energy plants (power purchase agreements, PPA) or direction connection to specific RE plants), the project had to work on the assumption of the status quo, which is that the weighted average carbon value of the public electricity supply is to be applied. For this reason, a standalone system (direct supply) was assumed in the model; i.e., the production of hydrogen is directly dependent on the feed-in of renewable energies at the regional level.[5]

The first step to this end consisted of determining the generation costs for RE electricity, green hydrogen and synfuels for each region. In this context, a region represents an area within a country that exhibits special potential for wind onshore, wind offshore, SCP or photovoltaics. The process of identifying the regions, their RE

[5] See also Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (RED II), paragraph 90.

potentials and their specific power generation costs was carried out for 88 countries using EnDAT from the DLR (cf. section 5.3). This data is incorporated into the trade model in the form of exogenous values. Existing potential is reduced by removing already existing capacities, starting with the potentials with the highest number of full load hours. The additional need to expand RE to include other sectors is taken into consideration via the three reference years of 2030, 2040 and 2050 in such a way that this primarily occurs in advance of hydrogen generation and the potential is reduced in the respective year, with the most economically favourable potential of the respective RE being utilised in each case. The entirety of the RE potential remaining in the analysed reference year is then available for the production of green hydrogen and synfuels, without taking into account future demand across all sectors. Stocks of RE and the need to expand them, as well as the demand for synthetic fuels, are borrowed from existing target scenarios:

- The results from the energy supply models in sub-project A.II are transferred over for Europe *(→ sub-report 6)*.
- For MENA, the results from the energy scenarios in sub-project B.I 100 per cent RE (scenario ADV) are applied *(→ sub-report 9)*.
- The expansion of RE and demand for green hydrogen and synfuels in the remaining countries are taken from the 1.5° target scenarios of the Global Energy and Climate Outlook 2020 (Keramidas et al., 2021).

Based on the same technical and economic assumptions as those used to determine the generation costs in section 5.3, costs are determined on an internal basis in the model for green hydrogen and synfuels, and propositions are obtained for all combinations between regions and countries, with the exception of existing embargoes. The model creates a merit order for each nation in which there is demand and determines which combination will make it possible to obtain the highest specific margin across all countries. In doing so, the margin is determined as the difference from the sequential national generation costs in the merit order and in relation to their potentials. If domestic supply represents the most advantageous option, and if these capacities are not capable of competing on the global market in order to achieve a higher margin than the equity yield rate assumed in the WACC, then supply is carried out on a domestic basis. Conversely, however, this means that an export is preferred if the margin turns out to be greater on this basis, and the domestic demand is met over the course of time with more expensive national capacities or with imports where applicable.

The supply with the highest margin is awarded the contract, and the potential as well as the existing supplies in the region are corrected according to the volume being awarded the contract. Allocation continues until the entire demand is met or feasible potentials have been used up. This process is applied to all three reference years taking into account the impact on the available potential.

A total of 12 scenarios was considered. These are based on the three demand scenarios ‘fuel mix’ (FM), ‘innovative drives’ (EL) and ‘classic drives’ (SYN) and were calculated using four WACC variations each (ref, pos, bau, neg) (see section 4.2).

- FM_ref, FM_bau, FM_pos, FM_neg
- EL_ref, EL_bau, EL_pos, EL_neg
- SYN_ref, SYN_bau, SYN_pos, SYN_neg

Key results

A significant result to be noted is that, under the given assumptions in the model, the MENA region would have only limited potential as a trade partner for the EU with regard to synfuels. Fig. 6-1 and Fig. 6-2 show that, across all twelve of the analysed scenario variants, trade with African countries would only take place in the FM_ref and SYN_ref variants. Depending on the quantities required globally, the EU supplies nearly half of its requirements itself and offers suppliers of synfuels from the Americas and Oceania very interesting margins and thus a high degree of supply flexibility compared with competitors as well.

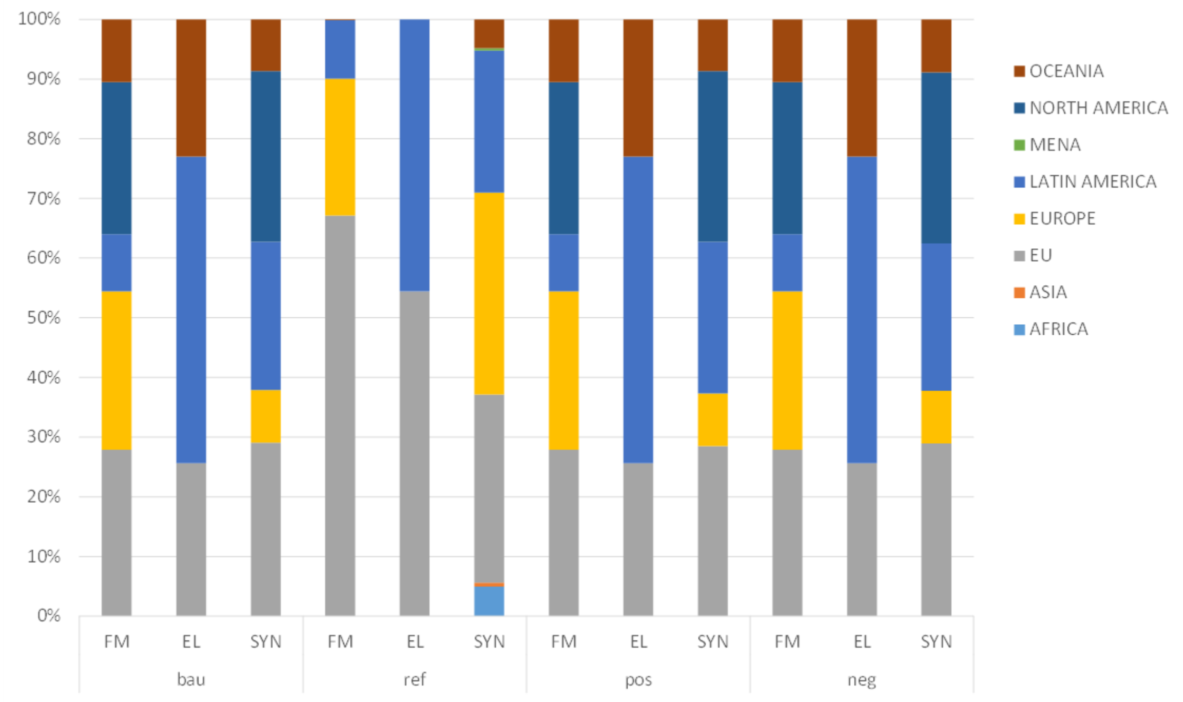


Fig. 6-1 Proportional supply of the EU with synthetic fuels in relation to the scenario variants in 2030

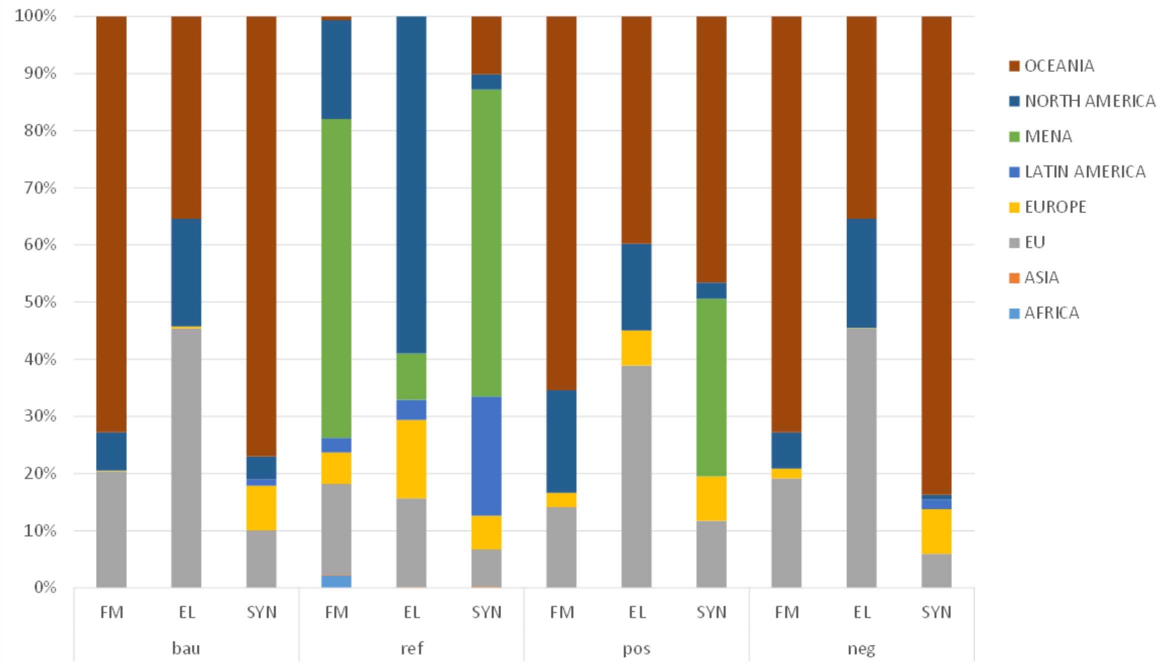


Fig. 6-2 Proportional supply of the EU with synthetic fuels in relation to the scenario variants in 2050

The same applies to Germany (see Fig. 6-3 and Fig. 6-4). If demand for synfuels involved lower and moderate volumes (scenarios EL and FM), the EU member states and the Americas would be the main suppliers for Germany up to and including 2040.

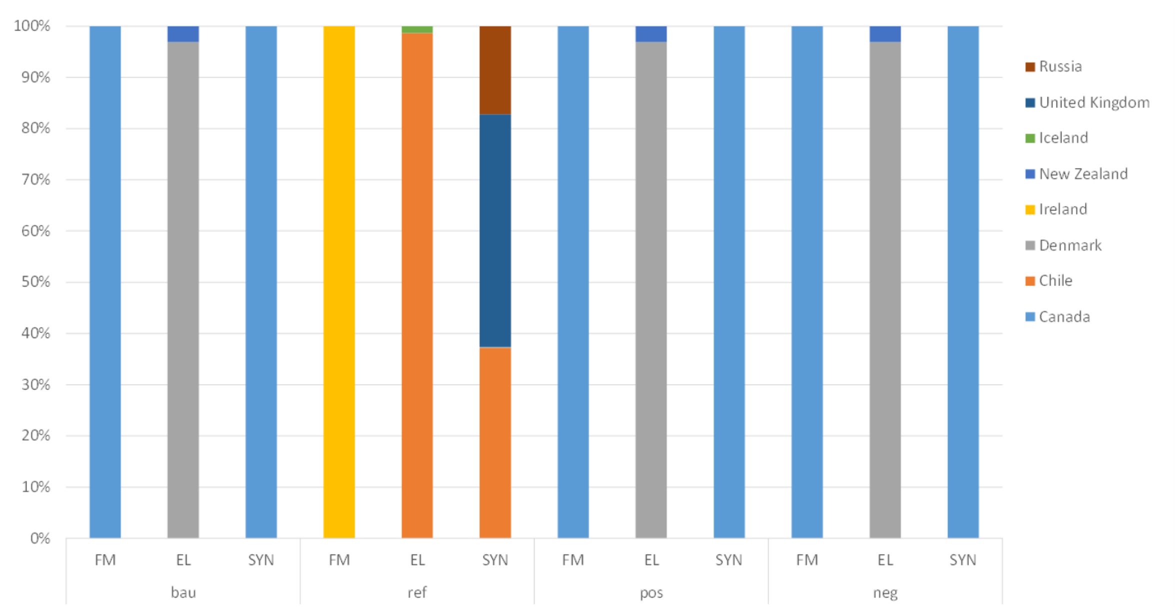


Fig. 6-3 Proportional supply of Germany with synthetic fuels in relation to the scenario variants in 2030

However, Australia would then take over a major share of the supply by 2050, with the exception of the Ref variants.

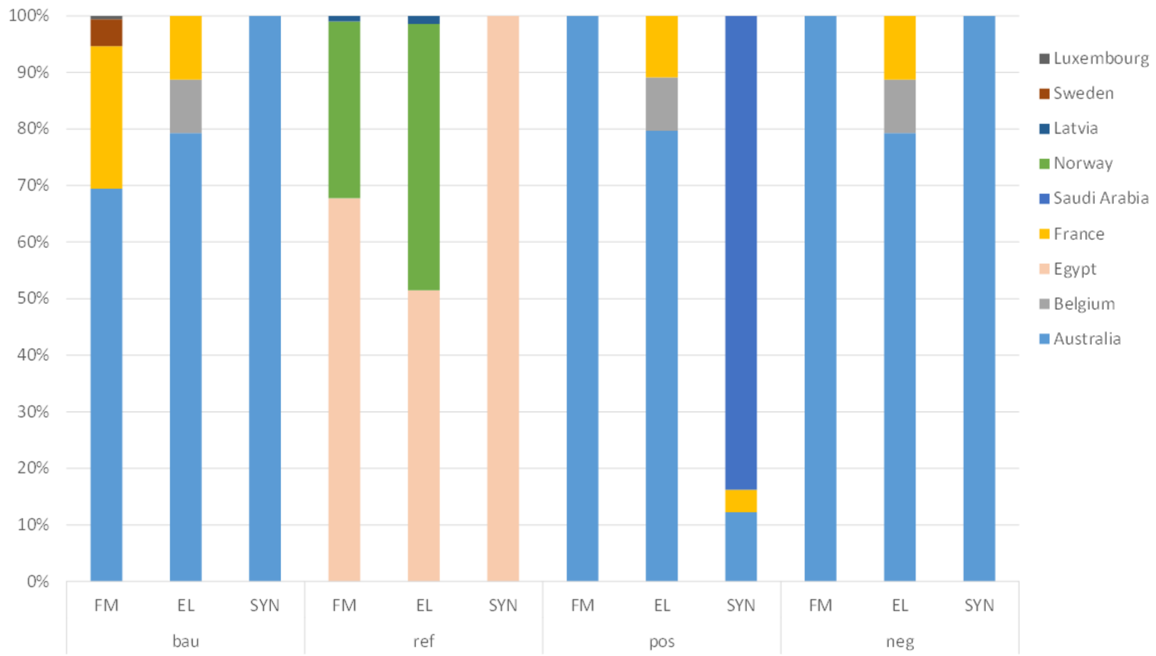


Fig. 6-4 Proportional supply of Germany with synthetic fuels in relation to the scenario variants in 2050

While it is absolutely the case that countries in the MENA region can exhibit large-scale, cost-effective RE potentials, other countries have lower WACCs and more affordable electricity generation costs for technological reasons due to a higher number of full load hours, especially with wind. Fig. 6-4 shows that, given the assumptions made here, the MENA region certainly has the potential to be a strong partner based on an improvement of the WACC in the WACC_pos variant or an alignment in the WACC_ref variant.

Taking PV in 2050 as an example, Fig. 6-5 shows that, for the WACC_bau variant, all countries located above the blue line could be potential suppliers for Germany. The line represents the average generation costs in Germany in 2050 and shows the relationship between WACC and full load hours at which the price can be maintained. Volume-weighted generation costs and full load hours for synfuels from PV systems were used as the basis for the figure. It appears, as is to be expected, that higher WACCs can theoretically be compensated for by higher full load hours and vice versa.

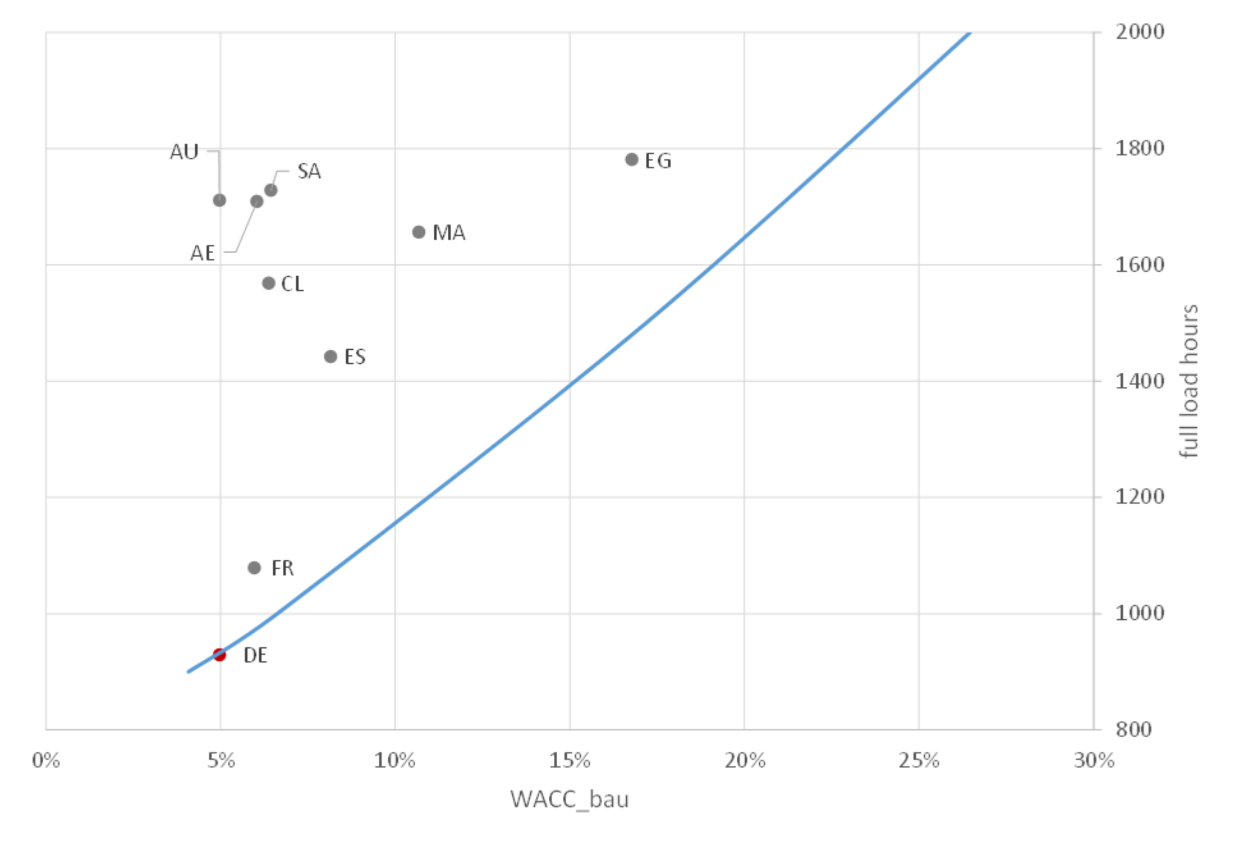


Fig. 6-5 Country comparison based on the relevant factors of WACC and full load hours for synthetic fuels on the basis of volume-weighted generation costs and PV electricity in 2050 in the WACC_bau scenario variant

The strong preference shown for Australia in the model is firstly the result of more affordable generation costs that are elicited by low estimated WACCs, together with very high full load hours, combined with the comparatively very low share that transport costs make up of the supplies for liquid energy sources. On the other hand, the current model is missing key Asian countries such as South Korea, Indonesia and Thailand that, due to their proximity to Australia, could attract a share of this country's potentials even if Europe appears to be more willing to pay over the long term and the potential in Australia is significant (cf. Fig. 9-2). In addition, the difference between the lowest quotes from Australia and the UAE to Germany is only around €20/MWh, and that between Australia and Saudi Arabia only around €10/MWh.

Due to the model's premise that preference would be given to the quote with the highest margin, even small differences are automatically significant; depending on the volumes being traded, however, these differences can also amount to several million euros for each transaction. Due to the fact that Australia offers very high potentials, only few purchasers remain for the other suppliers.

It is to be expected, however, that the first large trading volumes will be initiated via national bilateral partnerships and that government instruments can also have a minimising effect on the WACCs. Likewise, it appears unlikely that a single country would play this type of dominant role due to diversification. However, it should be expected that Australia and several countries in the Americas will become very important players in the international synfuels trade in future, simply due to their comparatively high and favourable potentials.

If, instead of synthetic fuels, only hydrogen is traded internationally, the transport costs take on key relevance due to its physical characteristics, and it is mainly imported from nearby regions via pipeline. Depending on the scenario, the EU primarily supplies its own demand, with the MENA countries only exporting significant volumes to the EU in the WACC_ref scenario variant. The bulk of the MENA countries' sales are made in the MENA region itself, in India and in the remaining European countries, especially Russia, Turkey and Ukraine. In Germany's case, the country is primarily supplied from windy neighbouring countries, although the countries included in this group are changing somewhat over the decades. The MENA region is only a significant trade partner in scenarios that have, by comparison, very high levels of demand. As with the scenarios involving synthetic fuels, a partnership with Egypt in particular has the potential to be advantageous in the WACC_ref scenario variants, where capital costs are consistent across all countries. This is because Egypt is home to high RE potentials and can offer them at more cost-effective rates than regional competitors at the same WACC due to higher full load hours for PV, CSP and wind.

A further outcome is that, given the assumed learning curves, it is almost impossible for facilities to remain economically feasible over a number of decades, even if, as assumed in the model, the first facilities in 2030 are primarily able to secure the locations with the highest numbers of full load hours. Should this prove to be the case, it can be expected that the prices at which energy is supplied will increase because the duration of the plants' service lives is assumed to be shorter.

6.2 Overall economic, socio-economic and environment-related distribution effects

This report section follows with some delay.

7 Integrative summary evaluation

7.1 Overall evaluation

Given the state of the art and supply costs of current technologies, assumptions regarding their development over the long term, available data on the resources in the MENA region and the models applied in this project, nine aspects can be noted that serve to answer to our key research question regarding the **MENA region's potential future role** in supplying Germany and Europe with RE electricity, hydrogen and synfuels.

1 | **Very high technical potentials for RE electricity, hydrogen and synfuels:** At approx. 413,000 TWh/a, the MENA region is home to very extensive potentials for the production of renewable energies, particularly as regards the use of solar energy (PV, CSP). Likewise, the potentials for producing hydrogen and synfuels are also very extensive, even once the long-term demand the MENA region itself would have for a complete conversion to renewable energies has been deducted. Compared with the potential demand for synfuels in Europe in 2050 with a broad degree of variation in the drive technologies, the possible export potentials are higher by a factor of 10 (from wind) to a factor of 210 (from solar). If the supply to Germany alone is taken into consideration, these factors are even 5.6 times higher.

2 | **Very extensive cost-effective potentials for RE electricity, hydrogen and synfuels:** Even if the potentials for renewable energies are unevenly distributed, nearly all MENA countries and regions exhibit significant production potentials with low generation costs and can thus be considered as an option for the production of synfuels. The PtL generation costs – calculated at average investment costs – amount to €1.92–2.65/l in 2030 and €1.22–1.65 /l in 2050 in the most advantageous locations (assuming that investment conditions in the region develop in a positive direction). The export potential for fuels that can be produced for less than €2/l amounts to approx. 26,000 TWh/a in 2050, even if investment conditions develop in a negative manner. In this case, the potential is primarily found in countries that are home to good technical potentials and stable investment conditions. This figure could even amount to approx. 48,000 TWh/a if investment conditions develop favourably.

3 | **Investment environment determines potential export regions:** However, the analysis also shows that the most cost-effective RE potential is not the only decisive factor in assessing possible export potentials from the MENA region – the investment environment also plays a crucial role in this. Taking investment risks into consideration in the countries in the MENA region has a significant influence on the costs of hydrogen and its downstream products and thus on the selection of the potential export countries. The risks were converted as country-specific weighted average capital costs (WACC). While country-specific WACCs have only been considered in the systematic evaluation of potentials to a very limited extent in the context of energy system models so far, this project estimated the investment risks for all the analysed MENA countries and factored them in accordingly for the first time. Nonetheless, it remains difficult to fully

quantify the country risk factors despite the conclusive results acquired in MENA-Fuels, and this quantification process is always highly dependent on current political developments, which also have the potential to change dramatically at short notice.

4 | **Complementary models with similar results:** While the results of the energy models described above are based solely on the analysis of generation costs, the trade model developed in parallel to this also includes trade restrictions (embargoes) and customs duties as well as analysing a wide range of other countries outside the MENA region. The trade model also arrives at the conclusion that, despite their low generation costs and very extensive export potentials, MENA countries would only become interesting partners for Germany and the EU if the capital costs for investors were to reach a level that gives them a genuine competitive advantage. Apart from this, the EU could, on the one hand, largely supply its own demand and, on the other hand, countries in the Americas and Oceania would come to play an increasingly important role as trade partners for the EU should global markets open up and become available.

5 | **Structure of general economic conditions is key:** In principle, there are two options that could be used over the medium term to also facilitate exports from countries that have cost-effective potentials but high risk-related costs: Firstly, risks for the renewable energy sector and the synthetic fuels sector could be reduced based on appropriate activities in the countries themselves. However, this could prove more difficult when it comes to macro risks such as general political and economic stability or in the event of unfavourable business conditions as a whole than it would be for micro risks that specifically relate to sector development and, for example, include the simplicity and speed of approval processes, available specialist expertise and general political priorities for the expansion of renewable energies. Secondly, national or multi-lateral financing instruments could be used to make capital available at lower costs. However, the influence of international financial institutions such as the World Bank, EBRD[6], KfW[7] and international risk mitigation mechanisms were not separately examined in the analysis.

6 | **Transporting energy sources plays a significant role:** As demonstrated by the results of the energy supply model, the amount of transport costs plays a key role when it comes to the type of product being transported (electricity, hydrogen or synfuels). As per the results of the model, the transport of energy from MENA to Europe across large distances would primarily take place in the form of hydrogen and synfuels. This is due to the comparatively low transport costs and the fact that generation potentials can be exploited more effectively at the production site. Electricity, on the other hand, would be (almost) entirely produced within Europe given that transporting electricity involves comparatively high costs.

6 European Bank for Reconstruction and Development

7 Reconstruction Credit Institute

7 | **Renewable energies need to be significantly expanded in the MENA region:** The work that went into the MENA scenarios showed that a GHG-neutral supply of energy of the MENA countries that does not involve fossil energy sources will already represent an enormous challenge in and of itself. Depending on the scenario, the estimated required expansion in generation capacities for solar and wind power to supply the region's own demand would amount to a total of 4,500 GW to just under 9,000 GW until 2050. The approaches taken in the current expansion goals of most MENA countries do not provide for these orders of magnitude and the expansion efforts required to this end. RE power generation in the MENA region for the export of synfuels should not be further expanded at the expense of the countries' own energy transition, as this would thwart efforts to achieve global targets. As a result, the RE **expansion targets** and developments must be stepped up to a significant extent in the potential export countries in the MENA region in the event of large-scale expansion of synfuels production. Ideally, both objectives – internal supply and exports – should serve to enhance each other.

8 | **All synfuels to be available at large scale by 2030 at the latest:** The technology assessment shows that nearly all of the analysed synthetic fuels could be produced at large scale by 2030 if the processes continue to be developed on an ongoing basis. Many of the required technologies such as sea water desalination, synthesis methods and the methanol-to-gasoline process have already reached a mature stage of development – the challenge often consists of integrating them with the production of electricity and heat from renewable energies. On the other hand, a great deal of development work is still needed for key processes such as carbon capture and use. The same applies to the further processing methods of LOHC coupling, methanol-to-DME, methanol-to-kerosene and methanol-to-OME, which, based on assumptions, will be available at large scale by 2030 or 2040.

9 | **Life cycle assessments show large reduction in climate impact:** When looking at the PtL process chains for producing synthetic kerosene via the Fischer-Tropsch and methanol routes, for which LCA were performed as an example, it is evident that the synthetic fuel has a significantly lower climate impact than the fossil reference. In the case that the CO_2 required for the synthesis was previously captured from the atmosphere, a reduction of greenhouse gases – depending on the pathway – of 57 - 84 % can be achieved. In all other categories of impact the synthetic fuel has poorer outcomes. This applies, for example, to the indicators of land use, terrestrial acidification, eutrophication and the cumulative energy demand. This is primarily due to the high energy requirements for hydrogen production and CO_2 supply, but also to the higher raw material requirements for the construction of the plants for the multi-stage process chains. It would also be more expedient to transport the final fuel rather than the required hydrogen across long distances. This would make it possible to reduce diffusion losses of hydrogen and utilise synergy effects created by integrating heat and water from the various sub-processes.

7.2 Limitations in the interpretation of the results

Due to the fact that the presented study was prepared as part of a technical funding initiative, questions relating to the potential implementation of the identified import pathways were not analysed. Among other things, this includes the required assessment of the export potentials of the MENA countries based on sustainability criteria, acceptance on the part of the local population, regulatory requirements for potential export strategies and the geopolitical classification as regards potential export countries. A wide range of micro and macro risks were only considered from various perspectives in the preceding risk evaluation. Other aspects that still need to be researched are outlined in section 10.3.

A further aspect to be noted is that MENA-Fuels was designed to be a research project based on a systemic analysis, with the project considering potential developments in the time period from 2030 to 2050/60 by constructing models, analysing scenarios and assessing technologies. Scenarios pinpoint 'if/then' developments and thus consider which developments could occur in light of the given assumptions. Depending on the range of assumptions, it is thus possible to outline a multitude of conceivable developments within which the actual developments can be expected to play out. For this reason, the results depicted here do not represent forecasts and are not suitable as a means of highlighting specific investment possibilities for companies or informing investment decisions. Rather, they are to be taken as insights that provide guidance for long-term decisions with time scales generally extending beyond 2030.

Moreover, the modelling did not take any specific, commercial projects in the MENA region into consideration. Such projects could serve as an indicator for long-term development if a corresponding trend (mass market, upscaling) were to be in evidence. However, given that the initiatives have typically involved pilot projects and, in many cases, only initial announcements thus far, they cannot be used as the basis for a long-term analysis of scenarios. In terms of costs, individual projects are likewise unsuitable for comparisons with the trends in costs assumed here, given that at this stage, they typically have yet to undergo the usual process of reducing costs based on technical learning, mass production and scaling effects. Rather, the influencing factors are much more likely to include state subsidies, purchase guarantees, favourable loans or internal financing options that are intended to boost entry into the market.

7.3 Dealing with uncertainties

As is typically the case in research projects, there are also uncertainties at a number of points in MENA-Fuels regarding the collected data. This particularly concerns statements regarding the development of future technologies, especially as the technologies considered here are still in development and will only be in use at large scale between 2030 and 2040. This aspect was taken into consideration where possible, for example by presenting costs as ranges rather than average values. Likewise, the corresponding sub-reports point out potential uncertainties in the results.

There is general uncertainty regarding forward projections of trends and developments over the course of a number of decades. In terms of MENA-Fuels, this concerns the future development of demand for fuel, the development of micro and macro risks in the MENA countries and future trade relationships. As noted above, this uncertainty was addressed via the conventional method of analysing scenarios. When creating scenarios, underlying development tendencies are outlined (known as story lines), with these narratives consisting of a wide range of different input parameters that are projected onward into the future. Rather than honing in on a certain development, the approach accommodates a range of scenarios that take into account various potential developments.

The more the results are aggregated, the more difficult it becomes to discern at which points which assumptions were made and how certain these assumptions are. Likewise, the results of the analyses regarding the supply pathways between the MENA region and Germany or Europe are based on a range of main assumptions that should be taken into consideration and followed up on when designing subsequent transition pathways. This applies, for example, to the identified potentials, particularly as regards available space and excluded areas, the utilised technologies, especially in terms of the degree of efficiency and cost assumptions, and the many different risk indicators of the MENA countries.

7.4 Innovative elements

In summary, the following innovative elements were implemented in the MENA-Fuels projects:

- A holistic assessment of various technologies for the production of synthetic fuels and raw materials highlights opportunities and risks involved in the potential introduction of power-based fuels at an early stage.
- Three demand scenarios point to varying demand for RE electricity, hydrogen and synthetic fuels for the transport sector in Germany and Europe.
- The project also took into account the materials required for a climate-neutral industrial sector, as these partially overlap with demand from the transport sector (hydrogen or raw materials such as methanol).
- In order to account for domestic demand in the MENA region, energy scenarios under which the 17 analysed MENA countries would be supplied with 100 per cent renewable energies were developed for the first time.
- In addition, generation costs for renewable energies and fuels were identified for the MENA countries and regions at a high degree of spatial resolution and transferred into cost-potentials.
- Optimising the pathways for the provision of fuels results in supply pathways with minimal costs between the MENA countries and Germany/Europe.
- A newly developed risk assessment was used to conduct risk analyses for the analysed MENA countries for the first time by using over 100 indicators to estimate both micro and macro risks.
- In addition, an approach was developed for transferring the risk assessments into country-specific increases in capital costs, which are incorporated in the weighted average capital costs (WACC).
- It was then possible to subsequently calculate supply pathways with minimal costs based on country-specific WACCs for the first time, as well as analysing changes

in them in light of generally positive and challenging developments in the countries under consideration.

- The project was able to analyse global supply pathways using a global trade model that orients trade towards the prospects for maximising profit and, in addition to production costs, also takes into account the WACC, transport costs, trade restrictions (embargoes) and customs duties.
- As part of short national studies, theoretical results for three selected countries were transposed onto the local infrastructural and industrial conditions, and relevant stakeholders and their interests were identified.
- The impacts of potential supply pathways were analysed from a macroeconomic perspective for the first time using a multi-regional input/output model.

8 Detailed presentation of assumptions and results

The assertions regarding the potential role the MENA region could play in future in terms of supplying RE electricity, hydrogen and downstream products, which were summarised in section 7, are described in greater detail below together with a range of assumptions.

8.1 Available potential for renewable energies and fuels in the MENA region

- The technical potentials for renewable energies were determined taking into account excluded areas, space-related factors and technological characterisations of the installed facilities. This yields potential electricity production amounting to 413,000 TWh/a, with very extensive potential from solar energy (PV, CSP) in particular. Even though the contributions from each MENA country vary considerably, nearly all of the MENA countries have significant potential for producing RE with low generation costs and can thus be considered for the production of hydrogen and synthetic energy sources.
- In keeping with this, very large potentials for producing RE are accompanied by very large potentials for producing fuels – even after deducting the long-term energy demand of the MENA countries. By comparison, the export potentials are ten (from wind) to 210 (from solar) times higher than the potential demand for synfuels in Europe in 2050 with a wide degree of variation in the drive technologies being used. If only the supply to Germany is taken into consideration, these figures are 5.6 times higher still.
- The potential for exporting fuels primarily comes from countries that are large in area. In small countries (especially Bahrain and Lebanon, but also Qatar, Kuwait and UAE), the domestic RE generation potential is exceeded in 100 per cent RE scenarios or is almost entirely or largely required to meet domestic demand. This demonstrates that import and export relationships for electricity and synthetic energy sources also need to be developed within the MENA region; these relationships are, for the most part, not addressed in the analyses presented here. The influence that domestic demand has on the costs of exported energies is based on the assumption that the most advantageous potentials will be used to meet domestic demand.

8.2 Generation costs for synthetic fuels in the MENA region

- The generation costs were determined based on a standalone facility, taking into account key required infrastructure. Production of the FT fuel is carried out continuously. The FT fuel is generated in close proximity to suitable export harbours, so additional costs for transport to the export harbour do not have to be taken into account.
- Provided the layout of the system components is designed for maximum cost-effectiveness, the results indicate that a majority of the costs are incurred at the RE plant at a rate of 43 to 57 per cent. The share is 17 to 22 per cent for storage components (battery or thermal energy storage and hydrogen storage units), 7 to 18 per cent for PEM electrolysis and 3 to 5 per cent for FT synthesis, including RWGS and hydrocracking. The infrastructure costs (power transmission lines)

amount to 3 to 9 per cent. Costs taken into consideration for water desalination and carbon capture amount to 3 to 5 per cent when using carbon separated from the cement industry or, in the long term, from cost-effective DAC facilities. There is a great deal of disparity in values taken from literature regarding the future costs for capturing carbon from the atmosphere with the help of DAC. As a result, the share of costs for carbon could increase the investment costs for DAC systems when higher assumptions are made.

- Because RE power generation makes up a large share of the costs, the RE technology has a significant influence on the fuel generation costs which, in the following section, refer to diesel fuel for the sake of simplification. Assuming average investment costs, the results indicate that starting generation costs in 2030 will amount to €2.00/l with PV, €1.92/l with CSP and €2.64/l with wind energy for the most advantageous locations in the MENA region if risks develop in a positive direction. Higher efficiencies and lower investment costs will result in lower generation costs over the long term – starting at €1.23/l with PV, €1.22/l with CSP and €1.65/l with wind energy in 2050. But even if risks develop in a negative manner, the generation costs remain similarly low for the most advantageous locations in countries with stable investment risks (Saudi Arabia, Kuwait, Qatar, Morocco, Oman and the United Arab Emirates) thanks to good technical potentials.
- PV and CSP generally yield similar fuel generation costs. While these costs nonetheless end up being marginally lower for PV at most locations, CSP is also identified as the most cost-effective variant at some locations.
- In reality, even lower generation costs could be achieved in comparison with the calculated values given that these are based on assumptions regarding average investment costs, which are very disparate in the literature. These could be significantly lower if minimal investment costs are used. In addition, a hybrid operation strategy (RE power mix) has the potential to reduce the high share of costs made up by the storage components, and thus the total costs, based on a better adjustment of the load curves.

8.3 Power generation technologies in the MENA region

- Solar energy (PV and CSP) in particular are suitable for use in the MENA region due to the high potential it offers along with low power generation costs. However, only PV technology is shown to be effective in the results of the energy supply model. This is due to the fact that the country-specific power generation costs for the PV technology (including the costs for storage units) are marginally lower than those for the CSP technology. As described in the previous section, CSP entails the lowest costs in only a few cases. These consists of costs that were modelled at a raster cell aggregation level exhibiting a higher degree of geographical resolution. PV technology proves to be the more economically attractive option from the perspective of the energy supply model that optimises techno-economic aspects only and does not specifically take into consideration power generation costs for individual raster points but rather on an aggregated basis for an entire country.
- However, a limiting factor to consider is that the potential advantages offered by variable CSP systems with thermal stores in terms of local security of supply (e.g.

providing guaranteed capacity or utilising waste heat) were not taken into consideration.

- In addition, all of the costs modelled for the future and thus also the differences in costs between the PV and CSP technologies are subject to uncertainties. On the whole, the results make it clear that both PV and the CSP technology could be highly significant in terms of producing power in the MENA region given that they offer high potential with low generation costs.
- Onshore wind energy also has relevance in the MENA region. However, the amount of affordable potential this technology offers is limited, due to which power generation from wind energy is comparatively low in comparison to solar energy. Due to its very low potential, which can only be utilised at comparatively high generation costs, offshore wind energy could not play a significant role in the MENA region.

8.4 Significance of national risks for the selection of potential export countries in the MENA region

- The results of the energy supply model show that two factors in particular have a decisive influence on the generation costs of hydrogen and synfuels and thus on the process of identifying potential export countries. These include, firstly, the advantageous technical potentials of renewable energies that were already described above and, secondly, the national risks, which are taken into consideration in the form of increases in capital costs.
- When considering national risks as a second influencing factor, it becomes clear that the development of both the renewable energy sector and the sector for synthetic fuels is dependent on a wide range of factors far exceeding purely cost-related considerations. On the one hand, these include *macro risks* such as the countries' general political and economic stability, which cannot be easily influenced. On the other hand, it is also vital to consider so-called micro risks that specifically relate to the development of the sector and, for example, include the simplicity and speed of approval processes, available specialist expertise and general political priorities around the expansion of renewable energies. The risk analysis showed that countries with higher risk figures exhibit poorer figures in the area of macro risks, such as internal or external conflicts or a poor overall business climate, which can have a substantial influence on the development of the sector. In addition, it can be assumed that it will be significantly more difficult to reduce the macro risks for countries than it will be to achieve improvements relating to micro risks. Specifically, it would not be possible to improve a country's economic situation as quickly as it would be to introduce or optimise adjustments relating to the implementation of projects. Despite this, a very favourable environment and attractive incentives for renewable energies and synthetic downstream products can also theoretically result in investments and development of the sectors even in a more economically or politically unstable country. Nonetheless, it is typically external instruments for minimising risk that are available in such cases, for example in the form of institutional financing or guarantees.

- Thus far, country-specific factors like these have only been incorporated into systematic assessments of the countries' potentials to a very limited extent. For example, the modelling of energy scenarios for all countries typically uses the same assumptions for capital costs or, at most, varies between one and three sets of capital costs (WACCs). However, the results presented here show that taking national risks into account in the form of country-specific increases in capital costs, which are incorporated into the WACCs, has a significant influence on the selection of potential export countries.
- The present study primarily identifies countries that are large in size and have lower WACCs compared with other countries in the region as well as mainly exhibiting lower risks as potential export countries. Meanwhile, the favourable potentials offered by smaller countries are primarily used to meet domestic demand. However, the results also show that it is not possible to make any clear statements regarding the preferred export countries, as these vary depending on whether focus is placed on assessing risks, the costs of risks, supply and demand potentials or the integration of trade flows.

8.5 Significance of imports from the MENA region for supplying Germany and Europe with RE electricity and synthetic energy sources

- As shown by the result of the energy supply model, imports of energy sources from the MENA region to both Germany and the rest of Europe have the potential to play a significant role due to the low costs of generating RE in the MENA region. From an economic perspective, preference should be given to the import of hydrogen and synfuels in particular due to their comparatively low transport costs. This likewise creates an opportunity for the MENA region to develop its entire value chain – from electricity production through to the synthesis process. Imports of electricity from the MENA region play a minor role due to the comparatively high costs of transporting electricity. Demand for electricity would be primarily covered for all countries worldwide by the production of electricity within Germany and Europe. These results apply for all three of the demand scenarios used and – given the assumptions of the system modelling carried out in the project – can thus be seen as robust as regards future trends in demand.
- When the investment risks described above are taken into consideration, the model points to increased production of energy sources within Germany and Europe and correspondingly lower imports from the MENA region. This is due to the comparatively low investment risk in many countries in Europe. The impacts resulting from a negative development of the investment risk in the MENA region were examined for the scenario based on moderate development of future demand for synfuels. In this case, imports would cease to play any role at all and the entirety of production would take place in Europe. This also shows that the RE potentials are sufficient for supplying Europe with RE electricity, hydrogen and synfuels on a fully self-sufficient basis under the assumptions that were made.
- If the influence of global trade on relationships between the MENA region and Europe is also included, countries from the MENA region will only come out on top in the trade model under the given assumptions if all WACCs are at the same

level or decrease significantly by 2050 in comparison with the current level. This applies to both green hydrogen and its synthetic downstream products.

8.6 Assumptions for the long-term domestic supply of the MENA region

- The domestic demand that could emerge in the MENA countries in light of the transition of their energy, transport and industrial systems was first identified in order to create scope for a climate-neutral economic system in the countries themselves. Two maximum scenarios were utilised to model a full supply with 100 per cent renewable energies, based on corresponding assumptions regarding the economic development of the individual countries. While energy demand in the transport sector would essentially remain at today's scale in a scenario that is very ambitious as regards efficiency and electrification (ADV), it would increase significantly in a moderate and potentially more realistic pathway (ALT). The development of energy demand for synthetic energy sources would vary accordingly.
- The quantity structures of the scenarios also show how varied the corresponding impacts on domestic demand for renewable electricity would be, estimated on the basis of the country-specific potentials only, i.e., without potential imports from neighbouring countries. In both cases, the requirements placed on the transition of the national energy systems and the expansion of production capacities would be enormous; in the case of the moderate scenario with higher demand for synthetic energy sources, it would be higher by a factor of 2 (ALT2 vs. ADV). A comparison with the countries' current expansion plans shows that these requirements are not even remotely taken into account in their energy policies as of yet and that a fundamental rethink in the direction of renewable energies would have to take place. A development of this type would also have to take place in order to create the required foundations for energy policies that would expand additional production capacities for energy exports.
- The countries' domestic demand determined in this manner was deducted from the technical potentials in advance when identifying the cost potentials of hydrogen and synthetic fuels. This was done by keeping the most advantageous potentials for renewable energies in reserve for domestic use, which means they were not included in the export potential of the respective country. As noted above, this reserved share makes up only a small percentage of the potential as a whole in countries that are large in size. In the small countries of Bahrain, Lebanon, Qatar, Kuwait and UAE, however, a very large proportion of the potential would thus be excluded from export and/or exports would not be realistic.
- At the same time, this assumption does not mean that the respective countries start by pursuing their own energy transition and only then export hydrogen and downstream products. Given that the transition is a long-term process, an expansion of VCs should ideally take place alongside this – involving domestic use of renewable energies and hydrogen (on the best areas available for this purpose) on the one hand and simultaneous creation of revenue (on areas that are not generally much less profitable) on the other hand. As a result, the export of hydrogen and synfuels already begins in 2030 within the energy supply model on which the project was based.

8.7 Amount of transport costs for hydrogen in comparison with synfuels

- MENA-Fuels also took into consideration the transport costs for the energy sources analysed in the project, with a focus on the transport of large quantities over large distances. Maritime shipping and, where applicable, pipelines are available for this purpose; transport to the nearest port was also taken into consideration for landlocked countries.
- Given that gaseous energy sources have very low volumetric energy densities under normal conditions, they are liquefied for transport by means of a cooling process. The volumetric energy density of hydrogen remains low even once it has been liquefied. Due to the processes required for its transport, the necessary insulation and potentially cooling as well as its low energy density, the specific transport costs for hydrogen are very high. This is particularly the case when comparing it with energy sources that are liquid under normal conditions, such as methanol or synthetic fuels, for which extensive transport expertise has already been built up. For example, the specific costs of transporting hydrogen from Morocco to Hamburg via liquefaction amount to some €47/MWh, compared with €1.8/MWh for methanol. It is important to note here that there is uncertainty around the numbers for hydrogen in particular given that the technologies to be used have yet to reach market maturity. This being said, the specific costs for transporting hydrogen will always remain comparatively high. For this reason, it appears appropriate to only transport hydrogen if it is also to be used as such in the destination country. If synfuels are required, many factors indicate that they should be produced directly from hydrogen on site and then transported. However, it is also important to consider whether greater differences in the costs for the ongoing processing of hydrogen are to be expected depending on the country and whether these differences are significant enough to compensate for the advantages in transport costs.
- A comparison of shipping and pipeline transport shows that, in the case of hydrogen, transport by pipeline could be more cost-effective than transport by sea in a large part of the MENA region. This would particularly be the case if it were possible to repurpose natural gas pipelines as hydrogen pipelines. Transport by ship may also prove to be cheaper for liquid energy sources in light of the low costs of using maritime traffic to transport them. It should also be noted that there is a significant amount of uncertainty around the costs of building new pipelines as well due to the fact that these costs depend on many different influencing factors such as population density, the geographical profile and soil conditions as well as the share of offshore pipelines and their costs in comparison to onshore pipelines.

8.8 Routes for transporting electricity, hydrogen and synfuels to Europe

- The transport of RE electricity, hydrogen and synfuels and the associated costs are explicitly taken into consideration in the energy supply model. In this context, transport by pipeline and tanker is considered for gaseous and liquid energy sources (only transport by pipeline is modelled for ammonia); for transport by pipeline, a distinction is made between onshore and offshore in order to accommodate the higher costs involved in offshore transport. HVDC lines are mapped in the model for electricity.

- The statements made above regarding transport costs are supported by the results of the energy supply model, which point to a general tendency of transporting hydrogen and synfuels. Transport of the gaseous and liquid energy sources is primarily carried out via pipelines for the distances that apply in the EUMENA region; liquid energy sources are also transported by tanker in small quantities, primarily over long distances. In terms of transport from the MENA region to Europe, the preferred routes are the onshore pipelines via the *Middle East* cluster to Southern Europe and via the *Maghreb without Tun/Alg* cluster to Western Europe – this is due to the lower transport costs involved in onshore versus offshore transport. However, it should be taken into consideration here that the break-even distance – that is, the distance at which the costs are the same for pipeline and tanker transport – is also subject to uncertainty due to the uncertainty involved in the data on transport costs. Sensitivity analyses on lower tanker transport costs in the context of the energy supply model and the results of the trade model indicate that transport by tanker can also represent an economically advantageous transport option for liquid energy sources in particular at the given distances in the EUMENA region.
- According to the results of the model, electricity is produced almost entirely within Europe. The transport of electricity is associated with comparatively high costs in comparison with the transport of synthetic energy sources, which makes it preferable from an economic standpoint to meet a major share of the final energy demand for electricity with inexpensive RE potentials within Europe.

8.9 Technologies for large-scale production of synfuels need to be developed

- The technology assessment shows that, even over the medium-term up until 2030, a majority of all the analysed synthetic fuels and industrial products could be made available at large scale via at least one pathway. This requires that the development of the processes to technical maturity be supported by research funding and other industrial policy measures. Many of the technologies required along the pathways have already been known for decades and are well developed or have even been in use around the world for many years on the basis of fossil energies. This is the case with sea water desalination or Fischer-Tropsch reactors, for example. The challenge here often consists of fully integrating them with renewable electricity and heat production, as this integration has not been extensively explored and tested as of yet.
- In contrast, other synthesis steps are still only minimally developed by comparison, even though they are key for the production of all downstream products based on renewables. This is particularly true of carbon capture and use. However, the development of the DAC method in particular that has been witnessed in recent years suggests that technical solutions for carbon capture from the air can also be expected to be available at scale by 2030, which could meet the demands for the production of synthetic fuels identified in MENA-Fuels.

- There is also the need for intensive technology development in areas where processes that have been favoured thus far along the PtX chains could in future be replaced by alternative processes offering advantages in terms of key aspects such as efficiency and economic viability. For example, the results of the technical assessment show that, in addition to HT electrolysis, solar thermal cycles (thermochemistry) in conjunction with CSP power plants (solar towers) offer the lowest hydrogen and thus synthesis gas costs over the long term. Combined with the high level of solar radiation potential in the MENA region, these technologies could thus represent relevant options as well. Current market activities indicate that they have the potential to be available sooner than has been discussed so far.

8.10 Environmental assessment of PtX pathways based on the example of synthetic kerosene

- All the analysed synthetic pathways achieved better results than the fossil references for 2050 in the climate change impact category (global warming potential, GWP) if CO_2 from direct air capture (DAC) is used, which is considered to be "climate neutral". The use of atmospheric CO_2 in the PtL routes – despite higher GHG emissions during the production phase – results in significantly lower net impacts for production, including CO_2 emissions from the combustion of the fuel, compared to the reference. Depending on the path, these correspond to a net reduction of 57-84%.
- However, disadvantages were found in all of the other categories of impact, particularly as regards land use (ALOP), terrestrial acidification (TAP), eutrophication (FEP) and the cumulative energy demand (CED). This is primarily due to the high volumes of energy required to produce hydrogen and to supply CO_2, but also due the likewise higher raw material requirements for the construction of PtL plants. The type of energy source and heat delivery emerge as the key success factors in terms of environmental impacts, with the use of exclusively renewable sources proving beneficial at sites with high numbers of full load hours.
- Transporting hydrogen over long distances involves high losses due to its diffusibility and therefore increased energy consumption as well. Producing hydrogen and fuels at different locations also inhibits the synergy effects of integrating heat and water from the various sub-processes. It would thus be more appropriate to transport the final fuel rather than the required hydrogen across long distances.

8.11 Global competition and the uncertainties it presents for business models

- The results of the trade model show that, based on the project’s assumptions regarding the conditions around potentials, WACC and trends in the cost of technologies, other countries outside the MENA region certainly have the potential to be strong competitors. Because it is assumed that all new technologies will have the same costs for all users and personnel costs are not taken into consideration, the key factors are the countries’ potentials and the WACC. In this same vein, individual countries do not have any advantage in terms of expertise that can be exploited in financial terms.

- Supply relationships change frequently in the free market assumed in the project. Apart from the scenarios in which a consistent WACC is used, the number of exporting countries (including domestic production) is modest. Some countries only start production in the 2040s because self-sufficiency or exports are financially unattractive prior to this. A number of countries such as the US, Canada, Ireland and New Zealand also show a high level of exports in many scenarios in the 2030s or 2040s. However, these then see a sharp decline again at the beginning of the 2050s due to a changing competitive situation.
- Given that maximising the margin is a major premise of the trade model, some constellations of scenarios also result in MENA countries being supplied by countries in the EU. This stems from the effect that potential providers located nearby in the MENA region with more affordable generation costs are already offering their resources to third parties. Generally speaking, however, the MENA region would be supplied by Australia and America. Only in the basic scenarios where the same WACC is used for all countries would Saudi Arabia and Egypt primarily supply the MENA region. However, these groupings have the potential to change if global demand for synfuels increases and chemical raw materials such as ammonia and methanol are taken into consideration accordingly in all demand scenarios.
- The assumed economies of scale nonetheless mean that many facilities do not maintain their competitive edge for very long when compared with new facilities. This experience, which was already gained in the production of PV modules, should be taken into consideration in any development of business models or in the planning of the facilities.

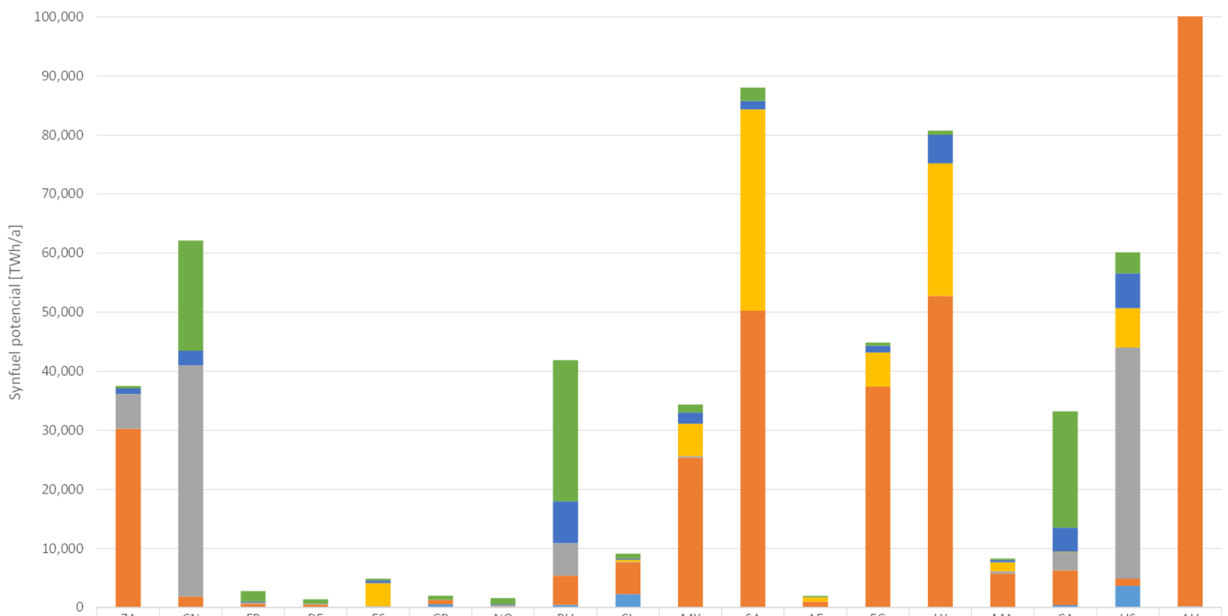
9 Potential for transfer to other supplier countries

Even though the analysis of potential supplier countries for Germany focuses on the sunny and windy countries in the MENA region, it is conceivable that other countries or regions could provide green hydrogen and synfuels (e.g. China, Chile, Australia, South Africa, Brazil). The research work carried out in sub-project B.II looked at this prospect, but an optimisation of the energy supply was not pursued in that case. Rather, the trade model zeroed in on the question of which other countries could be potential trade partners for MENA, Europe and Germany and how they influence trade within the system boundaries set around MENA and Europe in this project.

As described, both approaches – the energy supply model by the Wuppertal Institut and the trade model by IZES – come to the conclusion that despite offering low generation costs and very high potentials, MENA countries can only become attractive partners if the WACCs for the investors reach a level that creates an actual competitive advantage. Apart from this, Europe could and would largely supply its own demand, or countries in the Americas and Oceania would come to play an increasingly important role as trade partners should global markets open up. The trade model shows which countries this might include in various scenarios and thus provides valuable indications regarding the countries to which the energy supply model could be extended without losing significant momentum due to the inclusion of a very large number of countries.

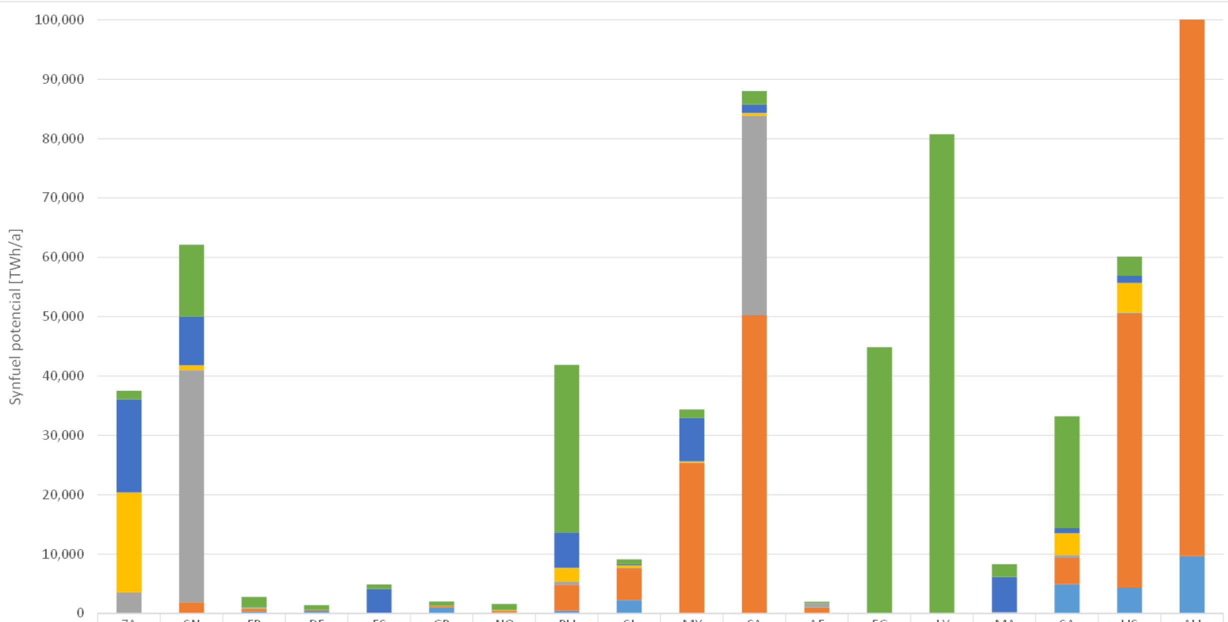
Fig. 9-1 and Fig. 9-2 complement Fig. 5-7 by showing several examples for cost-potentials in other countries. Country-specific synfuels potentials are represented in TWh/a in 2050 according to cost categories, in one case taking into account the WACC reference scenarios with the same WACC for all countries as well as in scenario WACC_bau, in which specific increases in costs due to risks were calculated on the WACC and kept at a consistent level for the future (see also section 6.1). Power generation capacities that are already available have not been deducted yet in the depicted information.

The factors that ultimately result in significant imports from Oceania are due to the fact that Australia possesses high potentials at the lower edge of the cost categories, while the potentials of other countries tend to be located in the middle or at the upper edge. It should also be noted that the overall demand of the countries analysed in the trade model for synfuels, partly including material use, amounts to approx. 6,750 TWh in the scenario with the highest demand for synfuels, which does not even correspond to a third of the potentials offered by the most inexpensive cost category, '< €1.25/l', in the WACC_bau scenario. The MENA countries make up only around 160 TWh of this figure. In the WACC_ref scenario, the supply of the most inexpensive cost category comes in at a lower figure of approx. 7.830 TWh due to the fact that a WACC of 6 per cent is assumed for all countries. Nonetheless, this supply is also less than the overall demand in the scenario with the highest demand for synfuels. However, the proportion of this made up by the MENA countries is more than doubled at a share of 350 TWh.



	ZA	CN	FR	DE	ES	GB	NO	RU	CL	MX	SA	AE	EG	LY	MA	CA	US	AU
	AFRICA	ASIA		EU			EUROPE		LATIN AMERICA				MENA			NORTH AMERICA		OCEANIA
2,00 - ...	382	18,671	1,780	764	318	715	1,053	23,866	807	1,359	2,247	248	542	722	241	19,709	3,553	3,539
1,74 - 2,00	996	2,474	193	27	419		107	7,095	215	1,913	1,424		1,152	4,847	411	4,069	5,907	9,631
1,63 - 1,74	43		13		3,908	-			383	5,459	34,106	735	5,791	22,453	1,551	86	6,650	116,162
1,50 - 1,63	5,809	39,135	153	79	190		246	5,525	59	279					399	3,081	39,172	10,645
1,25 - 1,50	30,280	1,815	515	454	17	769	165	4,942	5,408	25,304	50,244	988	37,376	52,743	5,719	5,873	1,210	218,289
< 1,25	2	39	119	52	26	521	10	445	2,262	68					9	416	3,644	214

Fig. 9-1 Country-specific synfuels potentials from renewable energies in 2050 divided into cost categories [€/l]; WACC_ref scenario (6 %)



	ZA	CN	FR	DE	ES	GB	NO	RU	CL	MX	SA	AE	EG	LY	MA	CA	US	AU
	AFRICA	ASIA		EU			EUROPE		LATIN AMERICA				MENA			NORTH AMERICA		OCEANIA
2,00 - ...	1,421	12,134	1,766	759	737	715	1,019	28,207	807	1,421	2,247	248	44,861	80,765	2,203	18,847	3,272	3,238
1,74 - 2,00	15,692	8,197	105	5	4,072		34	5,945	210	7,310	1,424				5,944	862	1,188	307
1,63 - 1,74	16,833	814	102	27	26	-	90	2,334	388	214	475					3,660	5,000	9,181
1,50 - 1,63	3,564	39,135	13		-		17	560	59	65	33,631	735			174	495	147	444
1,25 - 1,50		1,815	503	173	43	322	246	4,382	5,408	25,371	50,244	988			9	4,437	46,209	335,628
< 1,25	2	39	284	412	-	968	175	445	2,262	1						4,933	4,320	9,682

Fig. 9-2 Country-specific synfuels potentials from renewable energies in 2050 divided into cost categories [€/l]; WACC_bau scenario

However, even if the same countries are selected, a different result can be expected as regards the trade relationships between specific countries, simply due to the approach used by the two models. A joint analysis of the following pair of key aspects appears useful especially as regards the development of strategies to guarantee the security of supply at the political level but also in terms of the development of business strategies at energy companies (and those that utilise materials) given that this analysis compares and contrasts various targets (security of supply and maximisation of profits) and highlights reciprocal effects:

- How would the energy supply need to be structured in order to deliver a result that offers maximum cost-effectiveness for all national economies?
- How do independent companies do business on a global market, and what reciprocal effects does this have on national economies?

Provided that both models look at the same areas, future studies should follow up by including a critical evaluation that examines the economic, environmental and social correlations in detail.

Adding countries is unproblematic from a technical perspective; however, the optimisation algorithms used in the energy supply model are currently limited by a high degree of granularity, which meant that countries had to be grouped together as regions in some cases. Provided that sufficient information on other countries or regions is available, however, the approaches and methods used in this project are reasonably suitable for transfer to other studies.

10 Courses of action and required research

Strategic courses of action for **industry and politics** are then identified based on the results obtained thus far. In particular, these indicate which processes could be used to potentially import synfuels. Additional research requirements are also outlined, with these requirements also overlapping with the courses of action to some extent.

10.1 Courses of action for politics

A range of conceivable options could be used at the political level to pave the way for the MENA region's transition to an economically attractive supply region for comprehensive production and supply of green hydrogen and synthetic downstream products:

- In order to guarantee that investors have a high degree of planning reliability, **political conditions that are stable over the long term should be established for a market for green hydrogen and synthetic downstream products.** This particularly applies to regulatory issues, such as how sustainability is defined for hydrogen and synthetic fuels[8]. Firstly, this will involve specifying the conditions for the basic components of fuels (green hydrogen and climate-neutral CO_2 as well as their origins), and secondly, sustainability criteria need to be set out for the entire VC both in Germany as well as for export countries. For this reason, promoting the expansion goals and developments for renewable energies in the MENA countries must also be a major goal in any German and European energy policies aimed at imports, for example by providing support via energy and climate partnerships.
- A further aspect relating to planning security involves the **political stability and general investment conditions** in potential producer countries in the MENA region. These conditions can also be created if Germany not only supports potential export countries with the creation of beneficial conditions but also develops financing instruments and makes them available via German development banks (KfW) and guarantees (HERMES). Close coordination with international financing institutions is expedient here in terms of achieving coherence. Creating stable relationships at a bilateral or multilateral level in order to boost security and reliability for potential investors is of strategic significance if the MENA region is to develop as a supply region for green energy in the future. Even though this is already taking place to some extent, efforts towards this end must be significantly stepped up in order to enable rapid implementation and to secure the enormous amount of financing required not only for individual pilot projects but rather for entire sectors.
- However, the use of renewable energy **potentials within Europe** likewise should not be neglected. As demonstrated by the results of both the energy supply model and the trade model, Europe theoretically has the potential to be entirely self-sufficient – given moderate demand for synthetic fuels. The development of

8 A negative example is the regulation of biofuels, which has frequently been adjusted in the past.

energy partnerships with European countries could promote a rapid expansion of facilities and infrastructure in this context.

- This leads directly to the aspect of **security of supply**. It is important to weigh up how the supply pathways are to be diversified in future in the context of external energy policy. The result of this could be that trade relationships are not only developed with a few preferred countries but rather that a broader mix of export countries is selected from the outset. However, the aim could also be to make comprehensive use of the renewable energy resources in Europe for strategic reasons and not just based on economic advantages.
- If, on the other hand, a large share of the synthetic downstream products was to be imported from the MENA region due to good investment conditions, further **questions** would need to be discussed **from an industrial policy perspective**. Relocating the entire VC for fuels and intermediary products (such as methanol) to the MENA region (renewables pull[9]) would accelerate the transformation of the chemical industry in Germany to a significant extent. A great deal of research is still required here as regards the resilience of VCs. Early steps should be taken at the political level to develop an understanding of the future role of the chemicals industry and design instruments for **promoting** alternative **business models** (e.g. converting refineries to serve exclusively as 'feedstock refineries', building RE facilities and conversion plants, exporting know-how regarding technologies, joint ventures with the chemicals industry in potential export countries and, where necessary, targeted support for existing locations in Germany if this is called for in order to ensure security of supply).
- Generally speaking, **hydrogen and synthetic energy sources** should always be **considered in combination** from a political perspective as well, and strategies should not just focus on the import of hydrogen. The opinions of the international MENA-Fuels advisory boards made it very clear that the MENA region does not want to be reduced to the point where it is only a supplier of green hydrogen. In addition to the economic and technical advantage of directly transporting the synthetic downstream products rather than hydrogen, the development of entire VCs in the MENA region also involves issues around economic development which have an impact on the stability of a region that should not be underestimated.
- The range of cost-potential analyses as well as the approach for maximising profits taken from practice and integrated into the trade model make it clear that the import prices – after discounting in line with the current buying power – amount to roughly the same figures as current fossil energy sources prior to distribution and taxes. Hydrogen and synfuels will therefore only be used in locations where there is a lack of alternatives or corresponding willingness to pay. Due to sustainability aspects, it therefore remains sensible to make the most **efficient possible use of hydrogen and synfuels** and, in particular, to develop alternatives to them. In the case of the **mobility sector**, for example, this would not only

[9] For a discussion of renewables pull, see Samadi et al. (2021).

involve ongoing developments towards a change in drives but also designing a better **political framework** that offers incentives for a modal shift away from motorised transport, thus reducing demand for both fuels and raw materials.

- The most significant challenge here is likely to be the transition to a **climate-neutral aviation sector**. As demonstrated by the results of the life cycle assessment, the carbon-related climate impact of kerosene can be dramatically reduced with the use of synthetic kerosene based on renewable energies and carbon captured from the atmosphere. However, these emissions only make up around a third of the climate impact of the aviation sector, while the other two thirds result from non-carbon effects such as the formation of vapour trail cirrus. For this reason, the use of synthetic fuels can only make a limited contribution to climate neutrality in aviation. Research on alternative drives for air traffic should therefore be stepped up to a massive extent.

10.2 Courses of action for the industrial sector

Long-term planning security and framework conditions that facilitate investments in both political and economic terms provide an essential basis for industry as regards the systematic development and use of technologies, applications and business models. But a range of options that can support the transition to green hydrogen and synthetic fuels is also available to the industrial sector itself:

- The technology assessment raised numerous questions that have yet to be answered for a range of technologies (particularly in the case of the synthesis technologies but also as regards the production of hydrogen and carbon capture). These questions relate in particular to future technical development as well as downstream issues regarding an assessment in light of economic and ecological factors. One particular contribution on the part of the industrial sector would therefore consist of stepping up its **research and development efforts** to a significant extent in order to bring the technologies to market within short time frames and create scope for reductions in costs (based on technical learning, up-scaling and mass production). This development work should be open to all types of technologies in order to minimise the risk of failed developments and potential setbacks. Given that a range of technologies is being developed as part of the technical projects in the *energy transition in the transport sector funding initiative*, reference should also be made to the further recommendations in *BEniVer – accompanying research* in this context.
- Due to the urgent nature of the energy transition, the rapid **development of business models** is therefore required as well. Given that this project was based on a systemic analysis and highlighted the basic relationships for pathways for supplying Europe from the MENA region, the process of determining business models will require consideration on the part of the companies themselves to which the participating researchers can also contribute following the project's conclusion. Based on the results of the trade model, it is also evident that the pioneer plants of the 2030s and 2040s will scarcely last a decade without long-term **supply contracts** if the economies of scale assumed here for electrolysers and Fischer-Tropsch synthesis come to be. For this reason, business models should

definitely take into consideration the fact that the processes need to be adapted at short intervals to ensure they do not run into the same issues that the production of PV encountered in Germany.

- Likewise, this project did not include the planning of specific steps involved in **implementing the outlined transition pathways**. Even though this is not even possible yet at present, the basic direction and need for action have nonetheless already been set out by the adopted climate neutrality targets in and of themselves. Only a small window of time remains for implementing these, which means that, from the industrial sector's perspective, it is important to determine whether the massive expansion rates required for technologies are feasible and what activities will be necessary in order to ramp up production capacities to the 'giga-scale'.
- While Germany's industrial sector is very involved in the **development of synthesis technologies and hydrogen production technologies**, there is a lack of corresponding developments for **direct air capture** (DAC). Thus far, no related developments from the German industrial sector have emerged, even though the DAC technology is a key element for the production of climate-neutral synthetic fuels (and negative emissions in general terms) (Viebahn et al., 2019). Given that there is expected to be a significant amount of market potential and a large export market, Germany's industrial sector should consider making an entry into this technology of the future.
- As already observed in other research projects, the support provided to MENA-Fuels by the Industrial Committee proved to be very helpful and constructive. Generally speaking, however, the **collaboration between research and industry** for projects focusing on a systemic analysis like the current one could be even further enhanced in terms of creating a win/win situation. While academia requires robust data from the industrial sector as the basis for its modelling and technology assessments, and practical knowledge regarding promising markets can also support its analyses, it in turn provides knowledge that guides the industrial sector in determining the strategic direction for its developments. Even though they cannot serve as forecasts, scopes of scenarios (in terms of 'if/when analyses') at least highlight a multitude of potential developments for which the industrial sector should be prepared.

10.3 Need for research

Academia has a key role to play as a catalyst for innovations, particularly in the current phase involving the market launch and expansion of the capacity of a hydrogen and synfuels economy. In this context, it is important to pay attention to the **coherence and the diversity of the strategies** that can be derived from the outlined scopes of the scenarios in keeping with the **long-term goal of resilience and sustainability**. The focus on achieving the goal of defossilisation and decarbonisation of the transport sector in Germany and Europe and the diverse nature of the solutions do not represent a contradiction but rather form the basis for sustainable security of supply over the long term. In keeping with this, a wide range of research is still required so that the required strategies can implemented in a purposeful manner.

- The scenarios in the energy supply model build on earlier climate protection targets (95 per cent reduction in GHG emissions by 2050). Given that **more ambitious climate protection targets** have been set in the meantime, the analyses should be updated. This should include asking what implications the current goal of achieving climate neutrality in Germany by 2045 would have, for example as regards the necessary upscaling of the required plants, increasing the number of RE facilities at a more rapid pace, the earlier demand for climate-neutral carbon for the syntheses, etc.
- A great deal of uncertainty remains regarding the data on **transport costs**. Aspects that are dependent on this data include decisions regarding the type of transport (e.g. pipeline versus tanker for liquid energy sources) and, in particular, the degree to which the VC will be located in the potential export country (e.g. producing the end product as well versus transporting intermediate products or hydrogen). More accurate results could be obtained here based on more in-depth analyses and more detailed depictions of the transport costs.
- The energy supply model only models the transport connection between individual regions; transport within a region is not mapped. Likewise, concrete and comprehensive **infrastructure plans** cannot be created on the basis of these results. Questions that remain include, for example, whether the production of green hydrogen and synfuels should take place in proximity to renewable energy potentials, which are often located inland, or directly at export points such as ports or existing pipelines. Sources of carbon could also vary. In addition, an analysis needs to be carried out on **operating and site strategies** for the production of synthetic fuels and its impact on generation costs. Adapted strategies may be more attractive from the viewpoint of costs and lead to a reduction in generation costs. For example, distributing PtX system components at different locations, grid integration or hybrid RE systems (e.g. combined CSP/PV systems) can help to reduce costs for infrastructure, RE electricity and storage.
- Another question that remains to be answered is which countries will be able to meet the **ambitious requirements the EU places on green hydrogen and its downstream products** in future and what further changes this will lead to in the supply situation and potential trade partners.
- A modelling process designed to optimise costs was used to specifically determine potential import pathways in the context of MENA-Fuels. However, a more in-depth examination from the **perspective of the potential export countries** themselves that extends far beyond considering domestic demand in theoretical terms is required to make a realistic assessment of the export possibilities offered by individual countries in the MENA region.
  - This includes, firstly, questions regarding their specific economic and social **development potentials**, for example whether and how it will be possible to create local VCs in the context of or in conjunction with the expansion of export capacities for renewable energies.

  - However, local questions relating to sustainability should also be analysed, particularly with regard to satisfying the substantial demand for hydrogen.
  - A great deal of research still needs to be conducted in relation to the **factors that are relevant to selecting locations**, both from the perspective of investors as well as the individual countries. This should include scrutinising which opportunities can be exploited but also which barriers need to be broken down at the local level in order to develop a synthetic fuel sector.
- The results of these more extensive analyses would then need to be aligned with the results of the energy supply model and the trade model in order to determine **supply pathways** that, when viewed as a whole, may not be optimal in economic terms but are nonetheless **sustainable** from an overall perspective. At the same time, the numerous aspects that need to be taken into consideration also highlight the need to link questions relating to a **multi-criteria assessment** (of location factors) with the **modelling** (energy and trade flows).
- The '**system boundary**' of the analysis should simultaneously be expanded. This raises the question of how valid the results of the energy supply model relating to the MENA region are if relevant potential supply countries that are located further away, such as Chile or Australia, were also to be included in the analysis. A crucial factor is how these countries would fare as regards the three key deciding factors (generation costs for renewable energies, investment risk and transport costs) in comparison with the MENA region. The trade model developed in the research project offers an initial insight into this; however, it pursues a different optimisation approach than the energy supply model. In addition, these analyses need to be expanded to include the specific infrastructural requirements.
- The production of synthetic hydrocarbons from green hydrogen and CO_2 will also ultimately be linked with industrial policy goals in the MENA countries carrying out production. This could result in a **renewables pull effect** that, on the one hand, would open up positive development potentials for the MENA region. On the other hand, however, this would also create challenges in central VCs in the chemical industry in the EU that are currently based on petrochemical raw materials. These conditions would present both challenges and opportunities. More detailed impacts on and reciprocal effects with VCs have barely been researched thus far, despite their relevance for strategies in the industrial sector.
- In order to conduct more extensive analyses, the extent to which the measures required here to **reduce complexity** can be compensated for via other means as regards the number of modelled regions and the intrayear temporal resolution should also be analysed, for example by developing problem-specific solution processes in order to counteract the reduction in informative value that this would entail.
- Additional research also needs to be conducted in terms of explicitly **accounting for uncertainty** in the energy supply model. This would, however, further increase the complexity of the model; the developed solution processes would therefore need to be adjusted accordingly. A further aspect involves identifying so-

called coin-flip decisions and addressing them appropriately in order to enhance the informative value and robustness of the results.

- Likewise, only very approximate analyses of the **effects on the economy as a whole** were able to be carried out due to missing data, both as regards the economic effects of the supply pathways in Germany and Europe but, in particular, the lack of macroeconomic statistics in the MENA region. A separate, comprehensive research project would be required in order to fully map these effects.

11 List of references

Quoted literature

Agora Energiewende, Wuppertal Institut (2019). Klimaneutrale Industrie: Schlüsseltechnologien und Politikoptionen für Stahl, Chemie und Zement.

Bundesregierung (2021). Bundes-Klimaschutzgesetz (KSG). https://www.bmuv.de/gesetz/bundes-klimaschutzgesetz

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazillian, M., Roehrl, A. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. Energy Policy, 39(10), 5850–5870. https://doi.org/10.1016/j.enpol.2011.06.033

IEA (2017a). International Energy Agency (IEA): World Energy Balances 2017. OECD

IEA (2017b). International Energy Agency (IEA): World Energy Outlook 2017. OECD

Keramidas, K., Fosse, F., Diaz-Vazquez, A., Schade, B., Tchung-Ming, S., Weitzel, M., Vandyck, T., Wojtowicz, K. (2021). Global Energy and Climate Outlook. A new normal beyond Covid-19: estimating the effects of the pandemic on the energy system, with a focus on the transport sector. https://doi.org/10.2760/608429

Royal Institute of Technology (KTH), International Atomic Energy Agency, Energy Institute, University College London, Stockholm Environmental Institute (SEI), Stanford University, Paul Scherrer Institute, Energy Research Centre, University of Cape Town, North Carolina State University, United Nations Industrial Development Organization (UNIDO) (2022). Structure of OSeMOSYS. https://osemosys.readthedocs.io/en/latest/manual/Structure%20of%20OSeMOSYS.html

Samadi, S., Lechtenböhmer, S., Viebahn, P., Fischer, A. (2021). Renewables Pull—Verlagerung industrieller Produktion aufgrund unterschiedlicher Kosten erneuerbarer Energien. Energiewirtschaftliche Tagesfragen, 71(7–8), 10–13.

Scholz, Y. (2012). Renewable energy based electricity supply at low costs—Development of the REMix model and application for Europe. Universität Stuttgart.

Stetter, D. (2012). Enhancement of the REMix energy model – global renewable energy potentials optimized power plant siting and scenario validation. A thesis submitted to the Faculty of Energy Technology, Process and Biological Engineering of the University of Stuttgart in partial fulfillment of the requirements for the degree of Doctor of Engineering Sciences (Dr.-Ing.). Universität Stuttgart.

Teske, S. (Hrsg.) (2019). Achieving the Paris Climate Agreement Goals: Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C. Springer International Publishing. https://www.springer.com/gp/book/9783030058425

Viebahn, P., Scholz, A., Zelt, O. (2019). Entwicklungsstand und Forschungsbedarf von Direct Air Capture: Ergebnis einer multidimensionalen Analyse. https://epub.wupperinst.org/frontdoor/index/index/start/2/rows/10/sortfield/year_sort/sortorder/desc/searchtype/advanced/author_search/%22Zelt%2C+Ole%22+OR+%22Soukup%2C+Ole%22/author_searchmodifier/contains_all/doctypefq/article/docId/7438

Waissbein, O., Glemarec, Y., Bayraktar, H., Schmidt, T. (2013). Derisking Renewable Energy Investment. A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy Investment in Developing Countries. United Nations Development Programme. https://www.undp.org/publications/original-drei-report

Sub-reports

Acosta-Fernández, J., Viebahn, P., Hanke, T., Block, S. (2023). Gesamtwirtschaftliche Effekte von Investitionen zur Versorgung Deutschlands mit Wasserstoff und synthetischen Energieträgern aus der MENA-Region. MENA-Fuels: Teilbericht 13 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Braun, J., Kern, J., Scholz, Y., Hu, W., Moser, M., Schillings, C., Simon, S., Ersoy, S. R., Terrapon-Pfaff, J. (2022). Technische und risikobewertete Kosten-Potenzial-Analyse der MENA-Region. MENA-Fuels: Teilbericht 10 des Deutschen Zentrums für Luft- und Raumfahrt (DLR) und des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Doré, L., Krüger, C., Janßen, T. (2022). Weitere Szenarioanalysen: Berücksichtigung von Investitionsrisiken und Sensitivitäten der Basisszenarien. MENA-Fuels: Teilbericht 7 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Ersoy, S. R., Terrapon-Pfaff, J., Viebahn, P., Pregger, T., Braun, J. (2022). Synthese der Kurzstudien für Jordanien, Marokko und Oman. MENA-Fuels: Teilbericht 11 des Wuppertal Instituts und des Deutschen Zentrums für Luft- und Raumfahrt (DLR) an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Horst, J., Klann, U. (2022). MENA-Fuels—Analyse eines globalen Marktes für Wasserstoff und synthetische Energieträger hinsichtlich künftiger Handelsbeziehungen. MENA-Fuels: Teilbericht 12 des Instituts für ZukunftsEnergie- und Stoffstromsysteme (IZES) an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Jülich, A., Zelt, O. (2022). Ökobilanzen für synthetisches Kerosin—Vergleich von Produktionsrouten in MENA und Deutschland. MENA-Fuels: Teilbericht 2 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Krüger, C., Doré, L. (2022). Nachfrageszenarien – Storylines und Herleitung der Entwicklung der Nachfrage nach Synfuels und Grundstoffen. MENA-Fuels: Teilbericht 5 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Krüger, C., Doré, L., Janßen, T. (2022). Basisszenarien – Ergebnisse und Infrastrukturauswertung. MENA-Fuels: Teilbericht 6 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Pregger, T. (2022). Szenarien zur Eigenbedarfsanalyse für die MENA-Länder. MENA-Fuels: Teilbericht 9 des Deutschen Zentrums für Luft- und Raumfahrt (DLR) an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Saurat, M., Doré, L., Janßen, T., Kiefer, S., Krüger, C., Nebel, A. (2022). Beschreibung des Energieversorgungsmodells WISEE-ESM-I. MENA-Fuels: Teilbericht 4 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Terrapon-Pfaff, J., Prantner, M., Ersoy, S. R. (2022). Risikobewertung und Risikokostenanalyse der MENA-Region. MENA-Fuels: Teilbericht 8 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Viebahn, P., Kern, J., Horst, J., Rosenstiel, A., Terrapon-Pfaff, J., Doré, L., Krüger, C., Zelt, O., Pregger, T., Braun, J., Klann, U. (2022a). Synthese und Handlungsoptionen – Ergebnisbericht des Projekts MENA-Fuels. Teilbericht 14 des Wuppertal Instituts, des Deutschen Zentrums für Luft- und Raumfahrt (DLR) und des Instituts für ZukunftsEnergie- und Stoffstromsysteme (IZES) an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Viebahn, P., Kern, J., Horst, J., Rosenstiel, A., Terrapon-Pfaff, J., Doré, L., Krüger, C., Zelt, O., Pregger, T., Braun, J., Klann, U. (2022b). Synthesis and courses of action. Report on results of the MENA-Fuels project. Sub-report 14 to the Federal Ministry for Economic Affairs and Climate Action (BMWK). Wuppertal Institut, German Aerospace Center (DLR), Institut für ZukunftsEnergie- und Stoffstromsysteme (Institute for Future Energy and Material Flow Systems, IZES).

Viebahn, P., Kern, J., Horst, J., Rosenstiel, A., Terrapon-Pfaff, L., Doré, L., Krüger, C., Zelt, O., Pregger, T., Braun, J., Klann, U. (2022c) : synthèse et pistes d'action. Rapport sur les résultats du projet MENA-Fuels. Sous-rapport 14 au ministère fédéral de l'Économie et de la Protection du climat (BMWK). Wuppertal Institut, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für ZukunftsEnergie- und Stoffstromsysteme (IZES).

Zelt, O., Kobiela, G., Ortiz, W., Scholz, A., Monnerie, N., Rosenstiel, A., Viebahn, P. (2020). Multikriterielle Bewertung von Bereitstellungstechnologien synthetischer Kraftstoffe. MENA-Fuels: Teilbericht 3 des Wuppertal Instituts und des Deutschen Zentrums für Luft- und Raumfahrt (DLR) an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

Zelt, O., Scholz, A., Viebahn, P. (2021). Auswahl der zu bewertenden synthetischen Kraftstoffe und ihrer Bereitstellungstechnologien. MENA-Fuels: Teilbericht 1 des Wuppertal Instituts an das Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

12 Appendix: Advisory boards of the project

Table 12-1 List of members of the Industrial Advisory Board

Company	Member	Role
Afrika-Verein der deutschen Wirtschaft (AV)	Katarina Kunert	Consultant for North and Central Africa
Daimler Truck AG	Volker Hasenberg	External Affairs / Automotive Regulatory Strategy /Commercial Vehicles
Daimler Truck AG	Dr. Manfred Schuckert	External Affairs / Automotive Regulatory Strategy /Commercial Vehicles
DECHEMA e. V.	Prof. Dr. Kurt Wagemann	Head of Kopernicus Power-to-x project
Deutsche Post DHL Group	Dr. Henrik v. Storch	Senior Expert GoGreen
Deutsche Shell Holding GmbH	Jens Mueller-Belau	Energy Transition Manager Deutschland
EDL Anlagenbau GmbH	Dr.-Ing. Michael Haid	Managing Director
FEV Europe GmbH	Dr. Thorsten Schnorbus	Senior Project Manager Research and Innovation
INERATEC GmbH	Dr.-Ing. Tim Boeltken	Managing Director
Innogy SE	Dr. Frank-Detlef Drake	Head of Strategy and Technology
Innogy SE	Dr. Christian Lorenz	Senior Innovation Manager Research & Technology
MAN Energy Solutions SE	Dr. Matthias Auer	Head of Test & Validation
Raffinerie Heide GmbH	Dirk Burmeister	Managing Director Entwicklungsagentur Region Heide
Siemens AG	Dr. Michael Metzger	Principal Key Expert Energy Systems
Sunfire GmbH	Dr. Jens Baumgartner	Business Development Manager Electrolysis
Thyssenkrupp AG	Dr.-Ing. Hans-Jörn Weddige	Group Coordinator Energy, Climate and Environmental Policy
Uniper	Dr. Harald Hecking	Innovation Manager
Worley	Dr. Hans D. Hermes	Vice President Clean Hydrogen

Table 12-2 List of members of the international MENA-Fuels Advisory Board

Organisation	Member	Role
Acwa Power	Paddy Padmanathan	CEO
Arab-German Chamber of Commerce and Industry e.V. (GHORFA)	Abdulaziz Al-Mikhlafi	Secretary General
Association of Mediterranean Energy Regulators (MEDREG)	Hasan Ozkoc	Secretary General
Clean Energy Business Council MENA (CEBC)	Dr. Raed Bkayrat	Managing Director
Dii - Desert Energy	Paul van Son	Executive at innogy SE & Dii Desert Energy
European Investment Bank (EIB)	Mondher Chargui, Roland Schulze	Senior Energy specialist
International Renewable Energy Agency (IRENA)	Zoheir Hamedi	Regional Programme Officer - Middle East and North Africa
Middle East Gases Association (MEGA)	Roger Sayah	Secretary General
Regional Centre for Renewable Energy and Energy Efficiency (RCREEE)	Dr. Maged Mahmoud	Director of Projects and Technical Affairs
Union for the Mediterranean (UfM)	Grammenos Mastrojeni	Deputy Secretary General Energy & Climate Action
United Nations Economic and Social Commission for Western Asia (ESCWA)	Radia Sedaoui	Chief of the Energy Section
United Nations Industrial Development Organization (UNIDO)	Dr. Tareq Emtairah	Director of Energy Department

Overview of the MENA-Fuels sub-reports

All sub-reports (written in German) were placed on the following website during the second half of 2022: www.wupperinst.org/MENA-Fuels/

Teilprojekt A.I: Technologiebewertung für synthetische Kraftstoffe

1	Auswahl der zu bewertenden synthetischen Kraftstoffe und ihrer Bereitstellungstechnologien
2	Ökobilanzen für synthetisches Kerosin – Vergleich von Produktionsrouten in MENA und Deutschland
3	Multikriterielle Bewertung von Bereitstellungstechnologien synthetischer Kraftstoffe

Teilprojekt A.II: Potenzial- und Infrastrukturanalyse für EE-Strom, Wasserstoff und synthetische Folgeprodukte

4	Beschreibung des Energieversorgungsmodells WISEE-ESM-I
5	Nachfrageszenarien – Storylines und Herleitung der Entwicklung der Nachfrage nach Synfuels und Grundstoffen
6	Basisszenarien – Ergebnisse und Infrastrukturauswertung
7	Weitere Szenarioanalysen: Berücksichtigung von Investitionsrisiken und Sensitivitäten der Basisszenarien
8	Risikobewertung und Risikokostenanalyse der MENA-Region

Teilprojekt B.I: Analyse der Exportpotenziale in den MENA-Ländern

9	Szenarien zur Eigenbedarfsanalyse für die MENA-Länder
10	Technische und risikobewertete Kosten-Potenzial-Analyse der MENA-Region
11	Synthese der Kurzstudien für Jordanien, Marokko und Oman

Teilprojekt B.II: Künftige Märkte, Handelsprodukte und Wertschöpfungsketten

12	MENA-Fuels – Analyse eines globalen Marktes für Wasserstoff und synthetische Energieträger hinsichtlich künftiger Handelsbeziehungen
13	Gesamtwirtschaftliche Effekte von Investitionen zur Versorgung Deutschlands mit Wasserstoff und synthetischen Energieträgern aus der MENA-Region

Teilprojekt B.III: Synthese und Handlungsoptionen

14 (DE)	Synthese und Handlungsoptionen – Ergebnisbericht des Projekts MENA-Fuels
14 (EN)	Synthesis and courses of action – Report on results of the MENA-Fuels project
14 (FR)	Synthèse et pistes d’action – Rapport sur les résultats du projet MENA-Fuels

The future of mobility in Germany and the EU offers a wide range of technologies and solutions. In addition to electric mobility, the use of synthetic fuels represents one conceivable solution.

The production of large amounts of synthetic fuels (and feedstocks) requires substantial quantities of renewable energies at affordable prices. In particular, sunny and windy countries in the MENA region (North Africa and the Middle East) have the potential to serve as locations for producing synthetic fuels and their precursors due to the large potentials they offer in terms of renewable energies. In addition, trade relationships with and infrastructure already existing in many countries can be built up.

But what potentials are available in the individual countries? At what costs are corresponding resources available? What transport structures are required? What impacts do imports have on value creation both in Germany as well as in the MENA countries? What level of interest exists in the countries in the MENA region itself in terms of utilising their renewable energy potentials to supply their domestic demand but also for exports? What competitors need to be taken into consideration outside of the MENA region and the EU?

Taking these questions as its starting point, the MENA-Fuels project analysed the extent to which the MENA region can serve as a strategically relevant trade partner in supplying Germany (and the EU) with synthetic fuels or their precursors.

www.wupperinst.org/MENA-Fuels/