HYPAT

H_2 Potential

Global Atlas of H_2 Potential

Sustainable locations in the world for the green hydrogen economy of tomorrow: technical, economic and social analyses of the development of a global sustainable hydrogen atlas

HYPAT Working Paper 02/2022

Importing hydrogen and hydrogen derivatives: Export countries

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1 Introduction and objective

Hydrogen is becoming increasingly important as an energy source and feedstock for various energy and non-energy products over the course of the energy transition and in terms of climate protection as well as with a view to geopolitical strategies. In various scenarios, e.g., the long-term scenarios of the German Federal Ministry for Economic Affairs and Energy (BMWi) (BMWi 2021), and scenarios of the Ariadne Project (Luderer et al. 2021), a national demand for hydrogen is assumed, especially in industry and transport, which can probably not be covered by national production but will require hydrogen imports. There are similar scenarios for the EU(27), e.g., scenarios from the European Commission's Impact Assessment Report 2021 or the PAC Scenario of the Climate Action Network Europe (PAC 2020). This leads to the question of which countries are potential hydrogen suppliers from the perspective of Germany and Europe. A fundamental framework for the possible development pathways for hydrogen production is provided by the 2030 Agenda (Sustainable Development Goals SDG), the Paris Agreement and Germany's national hydrogen strategy as well as the European hydrogen strategy.

With the beginning of the war on Ukraine (March 2022), it became clear that the strategy for importing hydrogen as well as its derivatives and synthesis products needed to be redefined (HYPAT 2022). In terms of spreading the risk for strategic resources, a diverse group of supply countries should be considered, even if this could result in increased import costs. The German government has already taken important steps in this direction by entering into hydrogen partnerships with different countries such as Australia, Chile, Canada, Morocco, Namibia, Saudi Arabia, South Africa and, most recently, the United Arab Emirates. A major challenge when selecting supply countries is weighing up the various target areas such as environmental, social, political, human rights, resource and economic issues.

The objective of this study is to develop and apply a matrix analysis to assess potential hydrogen production and export countries. This matrix is based on sustainability requirements in the widest sense, i.e., economic, ecological and social sustainability.

In the following, the method used to identify potential countries for supplying hydrogen is presented to start with, which comprises an indicator-based analysis (chapter 2.1), and an approach based on expert knowledge (chapter 2.2). Chapter 3 presents the results of these two approaches (chapters 3.1 and 3.2.) and then discusses the results against the background of changes in the security policy assessment in the wake of the Ukraine conflict (chapter 3.3). The final chapter provides a brief summary of the approach and the results.

2 Method

A multi-criteria approach was chosen to assess the potential countries for producing and exporting hydrogen –referred to as H_2 countries in the following. This approach includes qualitative and quantitative indicators oriented toward the 2030 Agenda, the Paris Agreement and the German and European hydrogen strategies, as well as additional qualitative aspects that were collected in a discursive process and discussed by a group of experts. The approach comprises the following individual components:

1) Indicator-based analysis:
   - quantitative criteria, oriented on the following international agreements and national strategies:
   - 2030 Agenda with 17 sustainable development goals (SDGs)
   - Paris Agreement
   - Germany's national hydrogen strategy
   - qualitative criteria, which supplement the quantitative criteria and cover geopolitical interests, existing partnerships and strategies as well as current information on projects and studies.
2) Expert-based analysis: Expert knowledge about the various countries is considered and linked to the indicator-based analysis. This serves to validate the results of the first stage as well as adding supplementary information. The expert-based approach includes:
   - discussions of the H_2 countries in the project team and the HYPAT advisory board
   - focus group discussion on the H_2 countries with regional experts.

2.1 Indicator-based approach

This approach is based on using quantifiable data to assess a country as an exporter of H_2. The basic idea is to obtain a transparent and comprehensible ranking based on objective values by means of a comprehensive dataset on various evaluation criteria. The first step reviews to what extent hydrogen production in potential H_2 countries could have negative effects on compliance with or achievement of the SDGs and the targets of international agreements. The second step identifies minimum requirements with regard to resource availability and the political stability of a country, without which H_2 production cannot take place. The next step develops quantitative indicators per category – technology and resources, social, environmental, infrastructure, economic, political and societal - which are then used to assess a country as a H_2 country. Finally, these indicators are interlinked within the framework of a matrix analysis by initially assigning the same weight to all categories. Weighting factors that result from the focus group discussion with regional experts are only incorporated multiplicatively and additively in a second round of analysis.

2.1.1 Compliance

The use of hydrogen is a means to an end, primarily the pursuit of climate protection and sustainable development. Recently, the security of supply has also become more important. Most countries can already achieve greenhouse gas reductions of around 70 to 90% without following the more indirect route of hydrogen (BMZ 2021). Against this background, cooperation in the field of hydrogen must be aligned with international and national agreements. Germany's national hydrogen strategy (NWS) is of key relevance here. This was presented by the German government[1] in June 2020 after an intensive process of coordination between various federal ministries[2] and triggered the HYPAT research project among other things.

The NWS provides the framework for the production, transport, use and further application of green hydrogen in Germany. The German government acknowledges Germany's global responsibility to reduce greenhouse gas emissions. In this context, it was agreed in the NWS that hydrogen cooperation must support local energy transitions in partner countries and, especially in the case of developing countries, should not limit local energy supply nor trigger incentives for fossil energy sources. In addition, it should create sustainable growth and development opportunities.

The NWS explicitly refers to the Paris Agreement on climate change. Under international law, this treaty aims to keep the average global temperature rise well below 2°C compared to pre-industrial levels and to pursue additional efforts to limit the temperature increase to a maximum of 1.5°C. Financial flows should be attuned to this goal, including financial flows for investments in hydrogen infrastructures.

In addition, the global community has agreed on a socially, economically and ecologically sustainable transformation of national economies in the 2030 Agenda. It came into force on January 1, 2016 and runs for 15 years, applies to all member states of the United Nations and contains 17 sustainable development goals (SDG). These are supported by indicators and should be addressed as a whole, taking interactions into account. Examples include ensuring the availability and sustainable management of water and sanitation for all (SDG 6), access to affordable, reliable, sustainable and modern energy for all (SDG 7), building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation (SDG 9) as well as taking urgent action to combat climate change and its impacts (SDG 13). The 2030 Agenda has been incorporated into the design of the NWS. In particular, energy transition is understood as the transformation and, if necessary, expansion of an energy system in line with the 2030 Agenda and the Paris Agreement on climate change and thus as a climate-neutral and sustainable supply of sufficient energy for all (BMZ 2021).

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[1] Ministry names at the time the NWS was passed: BMWi – Bundesministerium für Wirtschaft und Energie; BMU – Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; BMVI – Bundesministerium für Verkehr und digitale Infrastruktur; BMBF – Bundesministerium für Bildung und Forschung sowie BMZ – Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung.

[2] Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry for the Environment (BMU), the Federal Ministry of Transport and Digital Infrastructure (BMVI), the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economic Cooperation and Development (BMZ),

The importance of collaborations in the field of clean (renewable) hydrogen with neighboring countries and regions is also emphasized in the European hydrogen strategy. This is why the topic of hydrogen should be prioritized on the foreign policy agenda. In particular, it should contribute to the transition to cleaner energy and foster sustainable growth and development. In view of natural resources, physical links and technical development, Southern and Eastern neighborhood countries should be priority partners. Ukraine and North Africa are mentioned as examples. The European Hydrogen Strategy's guidelines are basically in line with the NWS in Germany. However, the NWS specifies the framework conditions for potential collaborations in much more detail.

Given this background, the following fundamental guidelines are envisaged for hydrogen co-operations:

- They should not limit or pose a risk to local supplies of energy and water at any time.
- It must be ensured that no direct or indirect incentives for conventional power stations are triggered at any time. Instead, there must be synergies with local energy transitions.

Wherever possible, maximum synergies with the SDGs formulated in the 2030 Agenda should be implemented based on sustainable value creation chains.

The guiding principle should therefore be the installation of additional capacities for renewable energy and, if required, for water supply as well.

2.1.2 Minimum requirements

The minimum requirements for hydrogen production can be derived from the guidelines in the previous section. These minimum requirements primarily relate to a sustainable clean local energy supply and thus to natural resources for renewable energies such as sun and wind and water, as well as to political stability, which sets a reliable and robust framework for implementing clean energy generation. A country must meet these requirements to be considered a potential H_2 country – not only within the HYPAT project. These minimum prerequisites are specified in more detail in the following:

a) Renewable potential

Electricity from renewable energies is a key component for producing green hydrogen via electrolysis, which is why the renewable energy potential and the energy demand in 2050 were calculated for the different countries (for further details, see section 2.1.3 (Technical and natural aspects)). Hydropower, geothermal, wind and solar energy were taken into account. Demand was estimated based on current consumption and future developments and deducted from the generation potential in order to obtain the net potential. According to its national hydrogen strategy, the hydrogen demand in Germany will be between 90 and 110 TWh (BMWi 2020) in 2030. Therefore, a minimum net potential of 100 TWh with costs of up to 70 Euro/MWh was set as the threshold for countries to be considered for in-depth analysis. Selecting the cost threshold of 70 Euro/MWh is justified by the fact that slightly more expensive technologies such as solar thermal (CSP) and wind technologies are included for different countries, since the lowest cost levels mainly concern photovoltaics.

Based on this minimum requirement, a total of 118 countries/territories were excluded, whose net RE potential is below the 100 TWh mark. This list is shown in Appendix A1.1.

b) Water resources

The minimum requirements with regard to water resources take three criteria into account: a country's access to the sea, the available renewable water resources per person and year, and the drought risk within the country.

To assess water resources, the indicator "renewable water resources: total" of the SDG 6 Data Portal[3] and the total population in the associated year (2017) were taken from UN data[4]. A value for the available water resources per person and year was calculated from these data. Renewable water resources are defined as the maximum amount of annually available water in a country. This includes surface water and groundwater. The origin of the water may be inside or outside the borders of the country under consideration. The country is described as subject to water scarcity if water availability falls below the currently commonly applied threshold of 1,700 m^3 per person per year (Damkjaer et al. 2017).

The drought risk indicator of the World Resources Institute (WRI) is used to depict the drought risk of a country[5] (Hofste et al. 2019). This indicator combines data on risk, exposure and vulnerability and gives a probability for drought or droughts per analyzed region. The higher the value of this indicator, the higher the risk of drought in a country. The WRI classifies countries into risk categories, which range in steps of 20% from low (0% to 20%), low-medium, medium and medium-high to high (80% to 100%). For HYPAT's matrix analysis, countries with a drought risk of at least 60% were excluded from further consideration, if they also fell under the other two water-related exclusion criteria.

As a result, a country is excluded from further consideration in HYPAT if it

- is landlocked[6] and
- has renewable water resources of less than 1,700 m^3 per person per year at its disposal and
- a drought risk of more than 60% (risk categories "medium-high" and "high").

Burundi, Rwanda, the Czech Republic and Uzbekistan fall under these criteria and were therefore not considered further in HYPAT. There is no information on the drought risk for the country of Niger. However, it is landlocked and its available water resources are less than 1,700 m^3 per person per year. Therefore, Niger was also excluded from further analyses within the HYPAT project.

c) Political stability

Political and institutional aspects are the main factors driving the development and expansion of hydrogen production. In this context, it is essential to understand political stability as a multidimensional construct that not only considers the current political regime – its legitimacy, its behavior in terms of compliance with human rights and international law – but also the nature and effectiveness of state institutions. Five composite indicators were used within this analysis

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[3] https://www.sdg6data.org/maps

[4] http://data.un.org/Default.aspx

[5] WRI Aqueduct

[6] Also without access to the Caspian Sea

that are able to account for such a systemic approach. Four indices measure state failure in a wider sense, i.e., the inability or unwillingness of a state to fulfill essential core functions such as security and basic social services; while the World Bank's "Political Stability and Absence of Violence/Terrorism" indicator reflects the risk potential of states with regard to internal political conflicts. The indicators as well as the countries and period covered are briefly presented in Table 1.

With respect to each index, the 20 worst rated countries in the last available reporting period (*T*) were selected. To account for possible changes over time and to avoid distortion due to short-term outliers, time series data from 2005 onward were retrieved for these countries where available and relative changes were calculated within a five-year or ten-year interval prior to the reference period *T* (i.e., the most recent reporting period). The average of the relative changes between two consecutive years over the reporting period was also used as an additional trend indicator.

In a final step, it was determined where the individual data sets intersect by applying three different cut-off criteria. This resulted in different lists of countries that are perceived as politically unstable by a broad consensus:

1) Intersection of four indices (excl. Index of State Weakness, which is only shown for 2005) resulted in an exclusion of 10 countries (in alphabetical order): Afghanistan, Burundi, DR Congo, Iraq, Yemen, Nigeria, Somalia, South Sudan, Sudan, Central African Rep.
2) Intersection of all five indices resulted in an exclusion of seven countries: Afghanistan, Burundi, Iraq, DR Congo, Somalia, Sudan, Central African Rep.
3) Considering trends: countries under (1) and (2), that display a positive trend in at least one of the indices were considered after all and remained on the list of politically stable countries; this resulted in an exclusion of two countries: Afghanistan, Central African Rep.

We decided to apply the intersection of indices under 1) and thus exclude ten countries due to their political instability.

Table 1: Indices of political (in)stability

Index	Description	Publisher	Period covered	No. countries	Reference period
Constellations of State Fragility	Measures **state fragility** using three main aspects: 1) Authority: Ability to control violence; 2) Capacity: Ability to provide basic public services (such as access to clean water); 3) Legitimacy: Consent and freedom of the population (freedom of the press, upholding human rights etc.)	German Development Institute	2005-2015	171	2015
Fragile States Index	Measures **state vulnerability** based on 4 main dimensions and 12 conflict risk indicators: 1) Cohesion: Security apparatus, elites, group grievance; 2) Economic: economic decline, uneven development, human flight and brain drain; 3) Political: state legitimacy, public services, human rights and rule of law; 4) Social and Cross-cutting: demographic pressures, refugees and IDPs, external intervention.	Fund for Peace	2006-2021	179	2021
Index of State Weakness	Measures **state performance** in four critical spheres (economic, political, security and social welfare) using 20 sub-indicators: 1) Economic: economic growth, economic policy, support of private sector, fair income distribution; 2) Political: political institutions, legitimacy (accountability of government, rule of law, corruption, democratization, freedom of expression and association, bureaucracy); 3) Security: violent conflicts and their consequences, incidence of coups, political instability, political violence, human rights violations; 4) Social Welfare: food, health, education and access to clean water and sanitation.	Brookings	2005	141	2005
State Fragility Index	Measures state fragility in terms of effectiveness and legitimacy in four areas : 1) Security: war, state repression; 2) Political: stability and legitimacy of the regime/government; 3) Economic: GDP, export share of industrial goods; 4) Social welfare: human capital development and welfare	Center for Systemic Peace	1995 - 2018	167	2018
Political Stability and Absence of Violence/Terrorism	Measures **political stability** and **absence of violence/terrorism** using 352 variables, e.g. orderly transfer of power, armed conflict, internal conflict or social unrest and ethnic conflicts, social unrest, international tensions, political terror, security risk, government stability, interstate and civil war, human rights	World Bank	1996-2019	214	2019

2.1.3 Indicators

Various criteria can be derived from the SDGs as well as the PA, which can be used to illustrate sustainable H_2 production in the widest sense. These criteria are grouped into the categories shown below and described in detail in the following sections:

- Technical and natural resources that are decisive for the production of renewable electricity and hydrogen.
- Environmental aspects such as water availability, environmental protection and handling environmental pollution.
- Infrastructure that is needed to construct and operate H_2 generation plants as well as to transport the hydrogen.
- Social and institutional criteria such as political stability, reliable institutions, regulatory quality and effective governance, energy policies that contribute to politically and socially democratic framework conditions.
- Economic aspects include indices reflecting the product market and labor market situation, the financial system and risks with regard to investments and distributional aspects.

2.1.3.1 Technical and natural resources

Technical and natural resources comprise a country's capability to use existing technologies and resources for the production and transportation of hydrogen as well as the availability of natural resources to generate renewable electricity and hydrogen.

Renewable potential and energy demand

The net potential values result from the difference between future demand and existing renewables potential. The net potential values are given for different price levels from 20 Euro/MWh to 60 Euro/MWh in steps of 10 Euro/MWh.

- Potential of renewable energies

  Estimating the renewable energies (RE) potential was done using two different but complementary approaches: i) The generation potential of ground-mounted photovoltaic, solar thermal power (CSP), wind on land (onshore) and wind at sea (offshore) was calculated using the Enertile model. ii) The potential for geothermal and hydropower was determined from the literature.

  The Enertile model uses global weather data from the ERA5 reanalysis for the year 2010. The world is divided into about 12 million modeling tiles, each measuring 6.5 x 6.5 km^2. The type of land use is determined for each tile based on the GlobCover2009 data set. Then a utilization factor is defined for each land use category and each RE technology, which indicates what proportion of the area can be used for RE generation. The utilization factors used for this calculation are the same as those used in the Long-Term Scenarios Project.

Areas designated as protected area categories Ia, Ib and II according to the International Union for Conservation of Nature (IUCN) were not included when calculating the potential.[7]

A social discount rate of 2% was used for all the countries and technologies analyzed to calculate the costs of electricity generation. Further details on the methodology can be found in Lux et al. (2022).

- Energy demand

  In line with the SDGs and the PA, the domestic energy demand of potential export countries must also be met using CO_2-neutral renewable resources. For this reason, a country's renewable energy potential is adjusted by deducting the expected energy demand to obtain the so-called net potential. To estimate the energy demand, the primary energy consumption of the country in 2050 was taken from the 1.5°C scenario of the Global Energy and Climate Outlook 2020 of the JRC (European Commission 2020). This is a globally consistent and ambitious scenario for 23 countries and 14 aggregated world regions that covers energy demand throughout the time horizon up to 2050. For the countries not explicitly identified in this scenario, energy demand in 2050 was estimated based on the UN's population projection (medium scenario) (United Nations 2019), GDP per capita and the energy intensity of the GDP. GDP per capita and the energy intensity of the GDP in 2050 were derived in this case from historical figures for the year 2019[8] and the trend for countries in the same world region as reported in the JRC scenario. Using this approach, it was possible to estimate the future energy demand for 172 countries of the world and thus determine the net potential for renewable energies.

PV seasonality index

The seasonality index is the ratio between the highest and lowest monthly PV potential. A lower value reflects a more evenly spread potential over the course of the year. The data were taken from the monthly PV power output (PVOUT) potential calculated by the World Bank. PVOUT stands for the amount of energy (kWh) generated per installed photovoltaic capacity (kWp). The lowest value is in Haiti with 1.17. The highest value is in Norway with 14.97.

7 According to WWF (2008), Protected Area Category Ia includes strictly protected areas, where human visitation, use and impacts are strictly controlled and limited. They are primarily intended to protect biodiversity and geological or geomorphological features. Protected Area Category Ib includes so-called "wilderness areas". These are usually large areas, unmodified or only slightly modified by humans, whose natural condition is to be preserved. Protected Area Category II covers so-called national parks consisting of large natural or near-natural areas intended to protect large-scale ecological processes. National parks in the sense of the IUCN's Category II are, however, not the same as Germany's national parks and, in general, Germany's protected areas are not directly compatible with the IUCN's protected area categories. All of Germany's national parks are considered so-called development national parks (as of 2015), i.e., they are registered as Category II with the IUCN, but not all of them meet all of this category's requirements.

8 Enerdata Global Energy and CO_2 Data Market Data & CO_2 Emissions | Energy Database | Multi Energy Approach (enerdata.net)

Renewable energies – installed capacity

The current installed capacity of renewable energies per country was taken from the comprehensive review compiled by the International Renewable Energy Agency (IRENA). The data show the installed capacity for each technology at the end of the year. The data were drawn from various sources such as national statistics, reports of industrial associations etc. (IRENA 2021). The following technologies were taken into account: hydropower, photovoltaic, onshore and offshore wind power, wave/tidal energy, solar thermal power (CSP), bioenergy, solid biofuels, renewable municipal waste, other solid biofuels, biogas, geothermal. The total installed capacity was used for this study.

Exports of chemicals

The amount of exported chemicals was taken as a proxy for a country's technical capability in terms of producing and transporting chemicals. The source of the data was the World Bank's database on exports (The World Bank 2019). The United States is the main exporter of chemical products with USD 345 billion.

GCI: Technological readiness

This measures the respective country's general technical ability (qualification of the workforce and companies) to take up innovations and adopt them into its own production. The GCI[9] criteria form the ninth pillar of the global competitiveness index. The World Economic Forum data on competitiveness were used as the source (World Economic Forum 2017). Luxemburg has the highest value here.

Risk of disasters as the consequence of extreme natural events

The WorldRiskIndex states the risk of disaster as the consequence of extreme natural events (earthquakes, storms, floods, droughts and rising sea level) for different countries. The WorldRiskReport was used as the source (Bündnis Entwicklung Hilft 2021). It is divided into exposure and vulnerability. While exposure encompasses risks such as rising sea level, cyclones, earthquakes, floods and droughts, vulnerability comprises the following three components:

- Susceptibility: indicates the likelihood of suffering harm due to a natural event.
- Coping: indicates the capacities a society has to minimize the negative consequences of natural disasters and climate change.
- Adaptation: preventive (long-term) measures to mitigate the negative consequences of natural disasters.

With regard to the risk of disasters as a consequence of extreme natural events, Qatar has the lowest risk index value of 0.85. In contrast, Vanuatu has the highest risk index value of 82.55.

2.1.3.2 Environmental indicators

The matrix analysis uses environmental indicators to assess the environmental protection for a country in general. This considers the areas of land-use/protected areas, waste and wastewater, air emissions, biodiversity and water use/resources.

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9 Global Competitiveness Indicators

Protected areas

Analogous to the category "technical and natural aspects" in section 2.1.3, the protected area categories of the International Union for Conservation of Nature and Natural Resources (IUCN no date)[10] are also used for the environmental indicators. Areas classified as belonging to the protected area categories Ia, Ib and II are excluded for use by hydrogen production facilities and hydrogen infrastructure. The associated data are available in various formats, including GIS data, from the World Database on Protected Areas (WDPA)[11] and are updated continuously.

Based on the IUCN's definition of categories (see section 2.1.3 under natural and technical indicators), it would also have been possible to exclude all the protected area categories Ia-VI for use by hydrogen production facilities or associated facilities, as even the "weakest" category VI only allows "low-level non-industrial use of natural resources compatible with nature conservation". This would already exclude many areas and severely limit the potential for hydrogen production in terms of land availability in this first step of country selection. In addition, even though the protected area categories in Germany are not compatible with the IUCN categories, such a restrictive approach to protected areas would not correspond to the approach taken in Germany. The German Federal Agency for Nature Conservation (BfN) points out that protected areas are an important nature conservation instrument to preserve biodiversity and RE installations can have significant impacts and cause conflicts in terms of protecting species, preserving habitats and modifying landscapes, but it still reports the construction of RE installations within protected areas in Germany (except in national parks). However, the construction of RE plants in protected areas in Germany is approved on a case-by-case basis in accordance with the valid protection ordinances (Bundesamt für Naturschutz 2020). For the detailed country analysis, it is therefore recommended to review concrete locations for hydrogen production facilities, RE installations, seawater desalination plants or other plants associated with water supply with regard to the valid protection ordinances (see Lattemann 2010).

Waste management

As things stand at present, hydrogen production itself does not yield significant waste. However, other plants along the hydrogen value chain may well generate pollution due to waste or wastewater, for instance from the brine or salt concentrate of desalination plants. Therefore, the matrix analysis also includes indicators that assess the general handling of waste and wastewater within a country. The two indicators used are 'waste management' and 'water resources' of the Environmental Performance Index (EPI) from 2020 (Wendling et al. 2020). Each of these indicators is available for 144 countries. Both indicators give points from 0 to 100. A high value indicates a good assessment and a low value a poor one.

- The waste management indicator shows the proportion of municipal waste that is collected and further treated/reused in a controlled manner, e.g., through recycling, composting, incineration, landfills.
- The water resources indicator shows the proportion of wastewater that is subjected to at least primary treatment, taking into account the prevalence of wastewater sewer systems.

10 https://www.iucn.org/theme/protected-areas/about/protected-area-categories

11 https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA

These two waste management indicators supplement the "government effectiveness" indicator (World Bank), which is used for social and institutional framework conditions (see section "Social and institutional framework conditions"). This government effectiveness indicator includes "waste and wastewater management" that are determined by experts. The EPI indicators are quantitative indicators that complement this well. The EPI indicator for waste management is also used as an indicator for the quality of infrastructures.

Air emissions

The EPI's indicator "pollution emissions" from 2020 was used to assess the development of air emissions within a country (see Waste management). This indicator is available for 180 countries and, like the above-mentioned EPI indicators, also gives a score from 0 to 100 (high value: good assessment, low value: poor assessment). The indicator gives the average annual growth rate of SO_2 and NO_x emissions in the period 2005 to 2014. The gross domestic product (GDP) was included as a correction factor to prevent countries where emissions are strongly linked to GDP from scoring better than countries that have succeeded in decoupling emissions from economic growth.

During the research, additional indicators were collected on CO_2 emissions and shares of electricity imports, coal use, fossil and renewable shares in a country's electricity mix. However, these kinds of indicators were not considered here, because, on the one hand, they are difficult to interpret – a high fossil share in the energy mix could be interpreted as a pressure or motivation to act or as an obstacle or lock-in effect. On the other hand, such implications are better captured by the countries' national climate action plans (NDC), which are taken into account in the social and institutional framework (see the section on "Social and institutional framework conditions").

Biodiversity

The two EPI indicators "biodiversity & habitat" and "ecosystem services" from 2020 (see Waste management) were used to assess biodiversity within a country. Each of these indicators is available for 180 countries and also gives a score from 0 to 100 like the above-mentioned EPI indicators (high value: good assessment; low value: poor assessment). The biodiversity & habitat indicator provides a general assessment of protected areas and biodiversity within a country and is composed of several sub-indicators (terrestrial biome protection, marine protected areas, protected area representativeness index, species habitat index, species protection index, biodiversity habitat index). The ecosystem services indicator describes important ecosystems within a country and changes made to them. It is made up of sub-indicators on the loss of woodland and forest, grassland and wetlands.

Important conventions related to biodiversity include CBD[12], CITES[13] and Ramsar[14], among others. As these are taken into account in the social and institutional framework (see section "Social and institutional framework conditions") of the matrix analysis, they were not included among the environmental indicators.

12 https://www.cbd.int/nbsap/introduction.shtml

13 https://cites.org/eng/disc/parties/chronolo.php

14 https://www.ramsar.org/country-profiles

Water availability

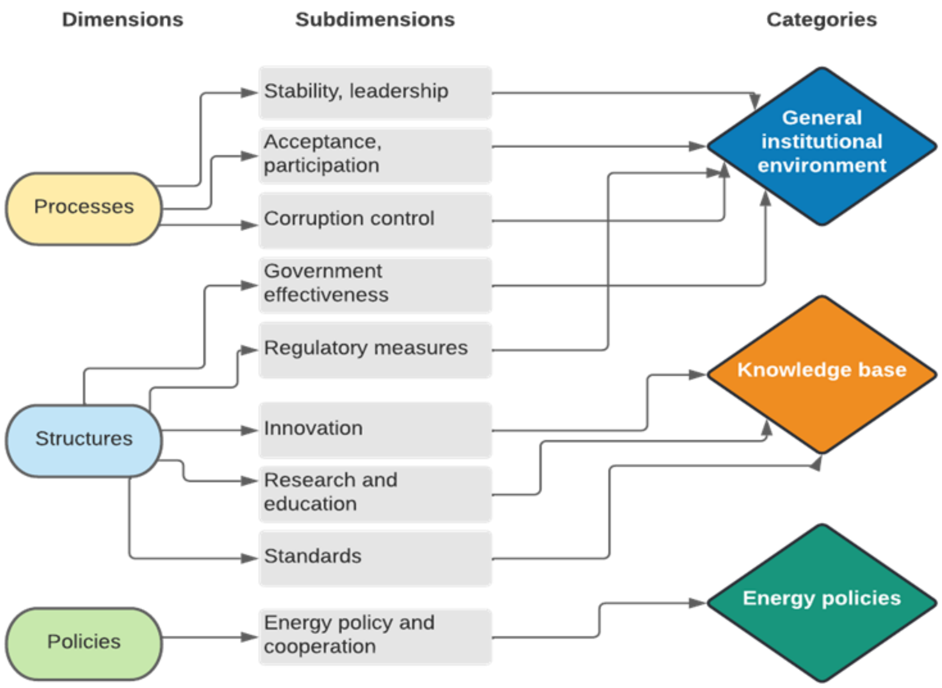
- The indicators used to assess the water availability within a country have already been explained in section 2.1.2 on the minimum requirements with regard to water resources. These are: i) country is landlocked or has access to the sea, ii) the WRI drought risk, and iii) the available renewable water resources per person and year. In addition, the baseline water stress indicator of the WRI Aqueduct Water Risk Atlas (2019) was used. This gives the ratio between water withdrawals and available renewable surface and groundwater resources as a percentage value. Water withdrawals refer to households, industry, irrigation and livestock. These include both consumptive and non-consumptive withdrawals. The latter usually find their way back into water bodies, usually downstream. These water resources are therefore not immediately available for use. A higher value of this indicator stands for greater competition for the use of water resources.

2.1.3.3 Social and institutional framework conditions

The institutional framework plays an important role in countries being able to unlock the potential of hydrogen production and use. To start with, the most important criteria influencing the energy transition were identified based on literature research on the impacts of institutional aspects on the generation and diffusion of renewable energies in developing countries. These include the quality of bureaucracy, existing institutional capacities and coordination as well the availability of skilled workers. As shown in Figure 1, the criteria were then grouped into nine areas, aimed at reflecting three dimensions of policy – content, structures and procedures. Finally, eleven indicators were selected to empirically measure these variables, which can be classified into three main categories:

1) General institutional environment
2) Energy policy
3) The generation, dissemination and standardization of knowledge.

Figure 1: Social and institutional framework conditions for a successful hydrogen economy



Source: own representation DIE

Table 2 provides an overview of the different categories, their associated indicators, the range of countries, the last available reference period and the link to the source.

Table 2: Selected indicators of social and institutional framework conditions. WGI: World Bank Governance Indicators; GII: Global Innovation Index; GQII: Global Quality Infrastructure Index

Category		Indicator	Number of countries	Quantitative /qualitative	Reference period	Source
General institutional environment	1	WGI Political Stability	214	qualitative	2019	http://info.worldbank.org/governance/wgi/
	2	WGI Government Effectiveness	214	qualitative	2019	http://info.worldbank.org/governance/wgi/
	3	WGI Rule of Law	214	qualitative	2019	http://info.worldbank.org/governance/wgi/
	4	WGI Voice and accountability	214	qualitative	2019	http://info.worldbank.org/governance/wgi/
	5	WGI Regulatory Quality	214	qualitative	2019	http://info.worldbank.org/governance/wgi/
	6	WGI Control of Corruption	214	qualitative	2019	http://info.worldbank.org/governance/wgi/
Energy policies	7	Signatories of the International Energy Charter (2015) and/or European Energy Charter (1991)	56	quantitative	2015/1991	https://www.energycharter.org/process/international-energy-charter-2015/overview/
	8	WorldBank RISE Renewable Energy Policy	137	qualitative	2019	https://rise.worldbank.org/scores
Knowledge base	9	GII Human Capital and Research	131	quantitative /qualitative	2020	https://www.globalinnovationindex.org/Home
	10	GII Business Sophistication	131	quantitative /qualitative		
	11	GQII Global Quality Infrastructure Index	180	quantitative	2020	https://gqii.org/

Source: own representation DIE

A brief description of the individual indicators is given below:

WGI Political stability

The "Political Stability and Absence of Violence/Terrorism" indicator of the WGI (World Bank Governance Indicators) database measures the perceived likelihood of political instability and/or politically motivated violence including terrorism.

WGI Government effectiveness

Government effectiveness captures the perceived quality of public services, the nature of the civil service and its independence from political arbitrariness, the quality of policy formulation and implementation, and the credibility of government commitment.

WGI Rule of law

The rule of law captures perceived confidence in and adherence to society's rules and norms, especially the enforceability of contracts, property rights and rule-of-law organizations.

WGI Voice and accountability

The voice and accountability indicator captures the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association and a free media.

WGI Regulatory quality

Regulatory quality captures the perceived ability of the government to formulate and implement sound strategies and regulations to develop and promote the private sector.

WGI Control of corruption

The control of corruption indicator measures the risk that public power is exercised for private gain, including corruption and the capture of the state by elites and private interests.

International Energy Charter

The International Energy Charter is a declaration of political intention with the objective to strengthen cooperation between the signatory states in the field of energy. As such, it reflects current energy policy issues such as the energy "trilemma", the role of developing countries in global energy security, and the need to diversify energy sources.

World Bank RISE

The World Bank's RISE (Regulatory Indicators for Sustainable Energy) database captures the policies and regulations of a country in the energy sector. The renewable energy field is illustrated using a total of seven indicators: planning for renewable energy expansion, incentives and regulatory support for renewable energy, attributes of financial and regulatory incentives, network connection and use, counterparty risk, carbon pricing, and monitoring.

GII Human capital and research

The GII (Global Innovation Index) composite indicator "Human capital and research" captures the knowledge base of a country, i.e., the level and standard of education (from primary to tertiary) and research activities. Primary and secondary education is measured by the spending on education and PISA results, among other things. Higher education covers enrolments in tertiary education as well as immigration and mobility of university students. The research and development index measures the level and quality of R&D activities using the number of researchers, gross expenditure and the quality of science and research institutions, among other things.

GII Business sophistication

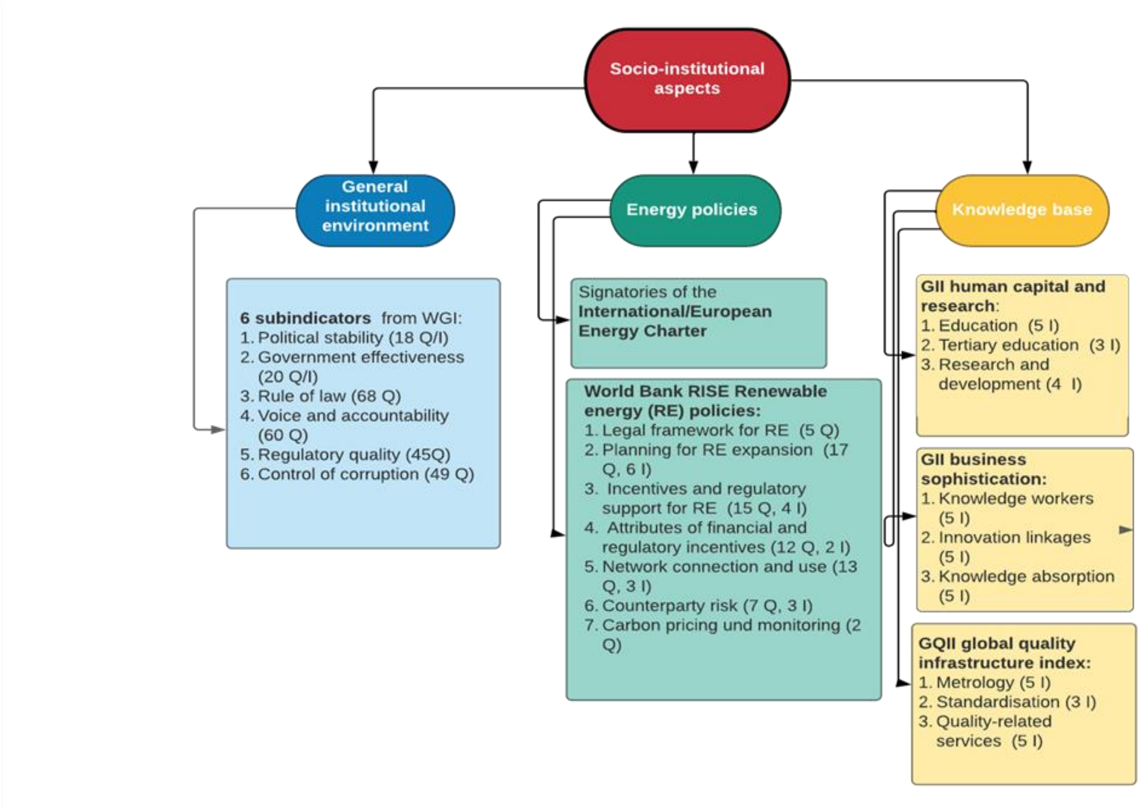
The "Business sophistication" indicator measures how conducive companies are to innovation activity based on three factors: 1) Availability of knowledge workers: measured by the demand for skilled workers, employment in knowledge-intensive services, further training possibilities and R&D activities in companies, among others; 2) Innovation linkages: measured by the collaborations between companies and universities on R&D, foreign R&D expenditure, the existence of clusters and joint patent applications, among others; 3) Knowledge absorption: based on intellectual property payments, high-tech imports, imports of ICT services, foreign direct investment, research talent in business enterprise, among others.

Global Quality Infrastructure Index (GQII)

The GQII (Global Quality Infrastructure Index) compares the quality infrastructure of different countries. The composition of the quality infrastructure is an important indicator for international trade and used for consumer and environmental protection. The indicator covers the international system of metrology, standardization, accreditation and quality-related services (testing, calibration, inspection, verification, training and awareness raising).

Figure 2 illustrates the structure of the selected indicators, especially the number of individual indicators (I) and the expert questions (Q) on which they are based.

Figure 2: Structure of the selected indicators for social and institutional framework conditions



Source: own diagram DIE

2.1.3.4 Infrastructure

Existing national infrastructure plays a major role when developing a hydrogen economy. An already well-established and well-functioning infrastructure makes it easier to establish new projects, operate plants and transport workers, raw materials and products both nationally and for foreign trade. In countries with comparatively poor infrastructure, higher costs and longer running times are expected for constructing production sites and hydrogen infrastructure and last, but not least, insufficient security of supply. Within the infrastructure category, the following subcategories are considered in more detail:

- Total area of the country (auxiliary indicator)
- Transportation via seaports
- Transportation via pipelines
- Transport distance to Germany
- Logistics factors

- Utility services

The reasons for selecting the indicators are also given and the top twenty countries per subcategory and indicator are listed.

Total area of the country (auxiliary indicator)

The country's total area was introduced as an auxiliary indicator in order to relate figures such as pipeline length and number of airports to the country's total area and thus to determine the respective densities, which make it possible to compare countries with each other. The values vary between 61 km^2 (San Marino) and 17.1 million km^2 (Russia) and are taken from the World Fact Book of the U.S. CIA (CIA n. d.).

Transportation via seaports

Seaport infrastructure enables the low-cost and flexible transportation of goods in solid and liquid form by ship. To measure how well developed a country's port infrastructure is, the following indicators were collected.

- *Ports*: This quantitative indicator gives the number of national ports in 2019; countries with no access to ports were assigned the value "0". The higher the number of ports, the better the initial conditions for the international movement of goods by ship. The maximum number of ports is 666 (USA). Figures are taken from the World Port Index (United States Government 2019).
- *Deepwater ports* are not subject to a strict definition. A relatively conservative study (Roa et al. 2013) assumes a minimum depth of 13.75 m, whereas the U.S Department of Transport (2020) does not give a depth, but only assumes the transportation, storage and handling of oil or LNG. In this case, deepwater ports are characterized by a channel or cargo depth of at least 9.5 m in order to allow large and fully loaded ships to dock. This study only counted ports sized "S" or larger in 2019 that are also ice-free all year round in order to exclude very small deepwater ports with insufficient loading equipment and to guarantee regular loading and unloading of larger quantities of goods. The maximum number of deepwater ports in a country is 71 (USA). The figures were taken from the World Port Index (United States Government 2019).
- *Oil and LNG terminals:* The numbers of national oil and LNG terminals in 2019 were considered separately and not included in the deepwater ports. These provide a direct indication that infrastructure in the form of pumps and pipelines is already in place that can be used to transport liquid hydrogen and its derivatives. Oil and LNG terminals are located offshore with a transport pipeline to the port. This means deliveries are also possible to shallow coastal areas. Similar to deepwater ports, only those oil and LNG terminals that have a minimum depth of 9.5 m and are ice-free all year round were considered. According to this definition, the maximum number of oil and LNG terminals is 105 (USA) (United States Government 2019).
- *Handling capacity:* The handling capacity records the nationally aggregated number of 20-foot containers handled at each port in 2019. This indicates international trade relations and the trading potential of national ports and pushes passenger transport into the background. This suggests port transportation logistics already exist for handling high volumes of goods. The maximum number of national 20-foot containers handled in 2019

was about 242 million (China). Figures were taken from the database of the World Bank (World Bank 2019).

Transportation via pipeline

- *National pipeline density:* Existing pipelines play a crucial role in the national transportation of energy carriers. Gaseous hydrogen can be transported via either newly constructed hydrogen pipelines or repurposed natural gas pipelines. Existing pipe routes and racks can also be used for new pipeline construction thus avoiding costly and time-consuming excavation and approval processes (Wang et al. 2021). In the future, it is also conceivable that hydrogen synthesis products with an oily consistency, such as Fischer-Tropsch products, could be transported using converted oil pipelines. Therefore, the total lengths of gas and oil pipelines were considered, further divided by the area of the country and then multiplied by 1,000 to compare countries in terms of pipeline length. The figures for 2007 to 2019 vary between 0.04 * 1,000 km/km^2 (Liberia) and 16,989 * 1,000 km/km^2 (Singapore) and were taken from the CIA's World Fact Book (CIA 2019).

- *Export connection to Europe:* This indicates the suitability of transporting hydrogen and its derivatives via existing gas and oil pipelines to Europe and to Germany, in particular. The pipeline routes were taken from the Open Infrastructure Map (OpenStreetMap Foundation 2019) and qualitatively assessed by the number of transit countries and the length of missing pipeline for a potential connection to Germany or Europe. The effort needed to obtain permits decreases with the number of transit countries. The smaller the length of additional pipeline needed for connection to Europe or Germany, the lower the investments in transport infrastructure for exports. An ordinal scale from 0 to 5 is used to rank these characteristics, where "5" stands for a very good export connection to Germany and "0" for no pipeline connection to Europe. This scale is described in more detail below:

  5 – The country considered is a neighboring country with a direct pipeline connection to Germany.

  4 – The country considered has a pipeline connection to Germany, which crosses one to two transit countries; or it is a direct neighbor with a very complicated pipeline route.

  3 – The country considered lies within Europe and has a pipeline connection to Germany, which crosses more than two transit countries; or it is a country outside Europe with a direct pipeline connection to Europe.

  2 – The country considered is outside Europe and max. 500 km of pipeline are missing for connection to Europe; or the country considered is within Europe and max. 500 km of pipeline are missing for connection to Germany.

  1 – The country considered has no existing pipeline connection to Europe. Max. 5,000 km of pipeline are missing for a connection.

  0 – The country considered has no existing pipeline connection to Europe. More than 5,000 km of pipeline are missing for a connection.

  Table 3 summarizes the ranking characteristics.

Table 3: Export connection to Europe and Germany by pipeline: ordinal scale with qualitative characteristics of ranking

Scale	European country – Connection to Germany		Non-European country – Connection to Europe
	No. transit countries	Length of missing pipeline	Length of missing pipeline
5	0	0 km	
4	1-2	0 km	
	0	0 km*	
3	>2	0 km	0 km
2	>2	≤ 500 km	≤ 500 km
1			≤ 5,000 km
0			> 5,000 km

* Note: complicated pipeline route

- *Gas storage reserves:* Large-scale storage systems make it possible to retain surpluses from the generation of renewable energies for times of low availability and therefore represent an important supplement to the transport infrastructure of hydrogen and its derivatives. Existing gas reservoirs that could be used to store hydrogen in the future were considered (Amid et al. 2016). Once depleted, oil and gas reservoirs will continue to be used for underground gas storage. Depleted gas reservoirs are preferred because their structure harbors fewer risks of leakage compared to oil reservoirs (Civan 2004). Natural gas reserves were estimated with reasonable security using analyses of geological and engineering data. The data on natural gas reserves are given for the years 2018-2020 and vary between 0 and 1,688 trillion cubic feet (tcf) (595 PWh, Russia), and were taken from the EIA's database (U.S. Energy Information Administration 2021).

Transport distance to Germany

- *Distance over land:* This indicator shows the distance over land from the potential export country to Germany to analyze the hydrogen pipeline potential. In most cases, the direct distance in km was taken as a quantitative value (similar to air routes). However, there are some exceptions for countries in South, Central and North America. The following criteria were applied:
  - Countries from South America were assigned a value of 22,189 km (Route: Bolivia-Panama-USA (Seattle)-Russia-Germany)
  - Countries from Central America were assigned a value of 18,829 km (Route: Panama-USA (Seattle)-Russia-Germany)
  - Countries from North America were assigned a value of 14,001 km (Route: USA (Seattle)-Russia-Germany)

  Another additional criterion was applied to countries/small islands that are a long way from the mainland (> 5,000 km). These countries were assigned a value of 25,000 km (maximum value), as pipeline connection is not possible.
- *Distance by sea:* In addition to transporting hydrogen via pipelines, the distances for transporting liquid hydrogen and its derivatives by ship were also surveyed. This was

done by determining the maritime distance from the country's nearest deepwater port or LNG terminal to the German port of Brunsbüttel. The maritime transport distances are given for the year 2021, vary between 405 (Netherlands) and 23,555 km (Micronesia) and were extracted from the Eurostat database using GitHub (GitHub 2021).

Logistics

Logistics should be understood as a network of services supporting the physical movement of goods as well as cross-border and national trade, which is the foundation for developing hydrogen trade. Logistics covers a range of activities beyond transportation, including warehousing, brokerage, express deliveries, operating terminals and managing the related data and information. The importance of logistics is measured by logistics performance, i.e., how efficient supply chains are on domestic and international markets. The sub-indicators customs, infrastructure, international deliveries, and quality and competence in logistics were taken from the World Bank report "Connecting to Compete 2018 Trade Logistics in the Global Economy" (the World Bank 2018). The subcategory of logistics was measured using the following five indicators:

- *Airport density:* Airport density compares the total number of airports or airfields with a specific area (in this case per 1000 km^2) that are visible from the air. The availability of airport infrastructure is of decisive importance for project management, as it enables access to areas where potential hydrogen projects are conducted. Information about the number of airports per country was combined with the auxiliary indicator of the total area of a country based on the CIA's World Fact Book (CIA 2022). Countries with at least one airport and an area of less than 10.000 km^2 were assigned the value 0.0066 as an exclusion criterion for airport density. (Appendix A),
- *Customs:* Customs authorities are responsible for documenting and collecting revenue from goods being imported into their respective country. The declared value of imported goods is the basis for collecting customs duties and value added tax for national budgets. Time taken is one of the main factors in customs services. The customs indicator is a qualitative one with a value ranging from 0-5 depending on the customs service of the respective country. A high value indicates that hydrogen derivatives can be delivered by ship without delay.
- *Infrastructure:* The logistics infrastructure is the backbone of the logistics system. Logistics services are provided globally under very different conditions. Alongside transport infrastructure, the suprastructure including logistics sites and real estate as well as telecommunications is becoming increasingly important for logistics. The infrastructure index shows how well a country is developed in terms of logistics or how well it is connected to the physical network of global logistics. The infrastructure indicator is a qualitative one that ranges between 0 and 5 for the respective country depending on infrastructure service and trade links between countries. A high value indicates that digitization and transparency are already in place for establishing a hydrogen economy.
- *International deliveries:* The quality of international shipments is a driver that influences the entire transport chain. Global trade of raw materials is very imbalanced: Most countries are either large net importers or large net exporters. This is reflected in transportation costs and ship movements. It is therefore critical to analyze the level of international shipments at competitive prices to understand the logistics quality. This is a qualitative

indicator measured on a scale from 0-5. A high value indicates that exporting hydrogen derivatives is feasible under competitive conditions.

- *Quality and competence in logistics:* The logistics quality and competence indicator paints a picture of the entire logistics supply chain. It provides information about the competence and quality of logistics services (e.g. transport companies, customs agents), the ability to track and trace shipments, and whether shipments arrive on time at their destination within the planned or expected delivery time. This is a qualitative indicator measured on a scale from 0-5. A high value indicates very high reliability for the shipment of hydrogen (derivatives).

Utility services

The utility subcategory describes the main factors supporting the construction of a hydrogen-gas infrastructure: quality of electricity supply, access to electricity, reliability of water supply, and waste disposal. The data were taken from the World Economic Forum's "Global Competitiveness Report" (World Economic Forum 2019).

- *Supply quality:* This indicator analyzes the efficiency of electricity transmission and distribution lines. Countries are ranked by losses (in %) in power transmission and distribution. The data represent estimates for 2016 and were collected by the International Energy Agency and the Energy Data Centre.
- *Electricity access:* The electricity connection indicator shows the percentage of the population with access to electricity. Data on electrification (2017) were gathered from industry, national surveys and international sources. Data for access to electricity were compiled from different sources, largely from nationally representative household surveys (IEA 2018). Access to electricity is essential, as electrical energy is needed to produce hydrogen, compress it for transport and synthesize it.
- *Reliability of water supply:* Water supply means the provision of water by public utilities, commercial organizations, municipal facilities or individuals, usually via a system of pumps and pipes. The reliability of a water supply system can be defined in terms of the shortages caused by failure of the system's physical components. A reliable water supply facilitates access to water as a raw material and coolant for hydrogen production and synthesis. A survey was conducted to assess this indicator, in which participants were asked to rate the reliability of water supply [1 = extremely unreliable; 7 = extremely reliable]. The data were collected in 2018-2019 in the World Economic Forum's Executive Opinion Survey.
- *Waste disposal:* Waste disposal is an important indicator for the overall assessment, which supplements infrastructures and falls under the environment category. This was developed as a new indicator in EPI 2020 and covers an important sustainability topic that has long been regarded as a notable gap in the EPI framework (EPI 2020). Uncontrolled waste disposal results in air and water pollution, soil contamination and increased risk of exposure to pathogens and toxic substances. Poorly managed waste also contributes to climate change through methane gas emissions and can be a threat to biodiversity. An established waste disposal system facilitates the construction of hydrogen production and synthesis plants for the removal of by-products and safe as well as hygienic working con-

ditions. The data measure the percentage of controlled solid waste (minimum: 22.6 % (Liberia), maximum: 88 % (Denmark)) of the waste generated, collected and treated in a way that controls its environmental impacts.

2.1.3.5 Economic framework conditions

Economic framework conditions have a major influence on the quality of a location and thus on the production conditions and competitiveness of companies. In addition to the policy areas of energy, and climate and environment, an important role is also played by the labor market, the availability and qualification of the workforce and related social issues, the financial market, the investment environment and free trade. These aspects are considered in more detail in the following sections. For each indicator, Table 4 lists the number of countries (N) for which the corresponding data are available as well as the distribution of the values according to minimum, maximum, mean and quartiles.

Product market, labor market, financial system

Indicators for the product market, labor market and financial system aim to provide information about how well the markets function within a country. These include aspects concerning the openness of trade, compliance with international labor standards, and financial stability. These aspects can be regarded as necessary requirements for ramping up a hydrogen economy.

The World Economic Forum's (WEF) Global Competitiveness Report from 2019 serves as the database for these indicators (World Economic Forum 2019). This report takes many sub-dimensions and associated indicators into account. At the same time, it provides an overview by aggregating these into overarching scores. The Global Competitiveness Report itself also draws on the Global Financial Development Database of the World Bank Group, the Financial Soundness Indicators of the International Monetary Fund and the Executive Opinion Survey of the WEF. It covers 141 countries – and thus more than 70 % of all the nations surveyed in HYPAT.

Reference is made specifically to the three scores described below, which each cover a range of values between 0 and 100. A score of 100 represents the "ideal state" according to WEF.

- The *Product Market Score* comprises equal shares of data on domestic market competition and trade openness, e.g., trade tariffs.
- The *Labor Market Score* is split equally between data on labor market flexibility and on meritocracy and incentives. Labor market flexibility includes the relations between employers and workers, for example, or the ease of hiring foreign workers. Meritocracy and incentives cover sub-indicators such as payment and productivity and the rate of income tax.
- Finally, the *Financial System Score* is included, which in turn is based on five sub-indicators. They include the availability of risk capital, market capitalization and the stability of banks, among others.

Some of the remaining categories of the Global Competitiveness Report were not included to avoid overlaps with other indicators in the project, such as in the case of infrastructure or institutions. In addition, several scores were excluded that only have limited meaningfulness when analyzing the hydrogen potential of a country, such as the size of the market in terms of gross domestic product, for example.

Freedom of investment

Developing a global hydrogen economy requires huge investments at home and abroad. Investment conditions and restrictions differ from country to country. These include different rules for foreign and domestic money flows and even closing certain industries to foreign investment. The *Investment Freedom Index* from the Heritage Foundation's Index of Economic Freedom 2021 is intended to show how freely investment capital can flow into the respective target country. Data on the freedom of investment are available for 180 countries.

The index can take a maximum value of 100, which represents an investment environment without any restrictions. The index covers 21 regulatory restraints in seven categories. For each restriction found in the investment regime of a country, points are deducted from the starting value of 100. The lower limit of the final index is set to 0 (this value therefore also applies to the few countries with a negative score). Examples of restrictions taken into account include "no transparency and burdensome bureaucracy", "no foreign purchases of real estate" and sector-specific limitations. Other sub-indicators of the Index of Economic Freedom, such as those concerning the institutional framework or openness of trade, are already covered either directly or indirectly in the matrix analysis and were therefore not considered twice.

International trade relations

Whether or not a country is a member of the World Trade Organization (WTO) is taken as an indicator of the intensity of trade relations and of the openness of trade and liberalization of the markets in a broader sense. The data set also contains a separate entry whether a country has so-called observer status. This status obliges the country to negotiate membership within the next five years. Currently (as of February 2022), the WTO has 164 member countries, 80 % of the countries analyzed at the start of HYPAT are members of the WTO.

Income inequality

The Gini coefficient was included as a measure of income inequality and as a possible normative indicator. The coefficient describes how household income distribution in a country deviates from a perfectly equal distribution. It covers a range of values between 0 and 100. A value of 0 means that everyone has the same income. The other extreme, a value of 100, means one household would have all the income at its disposal and the others nothing.

The source for the coefficients is the Human Development Report 2020 published by the United Nations Development Program. The value given for each country is from the most recent year available in the period 2010 to 2018. The relevant data are available for 152 of the countries analyzed here. The average value of the Gini coefficient for these 152 countries is 38. The lowest value in the HYPAT is sample is 24; the highest value is 63.

Wages

In addition, the national minimum wage was included as a highly simplified measure of the wage level. Specifically, this takes into account the most recently available value from the period 2010 to 2020 for the monthly gross minimum wage in U.S. dollars (US$) (converted using the exchange rates). The data were retrieved from the International Labour Organization. This variable ranges widely from US$ 2 to more about 4000 per month.

Risk capital costs

Investment risks and capital costs can decisively influence the economic efficiency and therefore also the implementation of hydrogen projects and its derivatives. So far, there is no standardized approach to determining the financing costs and risks at country level. HYPAT incorporates the estimated, country-specific *Equity Risk Premium* (ERP) in the analysis. This draws on the approach used by Damodaran (2021). The ERP is the result of adding a country-specific risk premium to a mature market risk premium. For the mature market premium, the ERP of the S&P 500 stock market index is calculated. The country-specific risk premium is based on data from Moody's rating, which classifies the credit risk of the respective nation. Depending on the rating of the respective national economy, a standard premium (rating-based default spread) is assigned. Finally, this is multiplied by 1.1 to account for stock market volatility. For the highest rating (AAA), this country risk premium is 0. For 160 countries in the HYPAT sample, it was possible to calculate an ERP, which ranges between approx. 5 and 24 %, and therefore indicates that countries differ significantly in this risk assessment.

Table 4: Statistics of economic indicators

Indicator	N	Min	Max	0.25 Q.	0.50 Q.	0.75 Q.	Mean
Product market score	139	35	81	49.7	54.6	60.9	55.0
Labor market score	140	41	81	53.3	59.5	65.7	59.9
Financial system score	140	29	91	51.0	59.8	71.3	62.2
Investment freedom index	180	0	95	45.0	60.0	73.8	56.4
WTO membership	195	0	1				0.8
Gini coefficient	152	24	63	32.7	37.0	42.8	38.1
Minimum wage (USD)	128	18	44433	111.0	252.7	848.0	2036.2
Equity risk premium	160	5	24	5.9	8.2	11.0	9.3
Note: 195 countries were considered. Column N shows the number of existing observations (number of countries minus missing figures).							

2.1.4 Multi-criteria evaluation

The indicators described above form subcategories within the respective categories. Not every category and subcategory includes the same number of indicators. This results in an indirect weighting of the indicators within the respective category. Table 5 below presents the indicator grouping per subcategory and category.

Table 5: Overview of indicators and their assignment to subcategories in the evaluation tool

Category	Subcategory	Indicators
Natural and technical resources	Net renewable potential	RE net potential: • Total potential • Potential below 20 Euro/WMh • Potential below 30 Euro/WMh • Potential below 40 Euro/WMh • Potential below 50 Euro/WMh • Potential below 60 Euro/WMh
	Additional natural resources	PV seasonality

Category	Subcategory	Indicators
		World risk exposure
	Technology development	GCI Chemical exports Installed renewable installations
Environmental	Waste management	EPI Waste management EPI Water resources
	Air emissions	EPI Pollution Emissions
	Biodiversity	EPI Biodiversity & Habitat, EPI Ecosystem Services
	Water availability	Renewable water resources Landlocked country WRI Drought Risk WRI Baseline Water Stress
Infrastructure	Ports	Ports Deepwater port density Oil/LNG terminals Handling capacity
	Pipelines	Domestic pipeline density Gas storage reserves Export connection with the EU
	Transport distances	Distance across sea Distance over land
	Logistics	Customs Infrastructure Airport density International shipments Logistics quality and competence
	Utilities	Access to electricity Quality of electricity supply Reliability of water supply Waste disposal
Social-institutional	Institutional framework conditions	Political stability Government effectiveness Rule of law Voice and accountability Regulatory quality Control of corruption
	Energy policy	Energy charter RE policy
	Knowledge base	Human capital and research Business sophistication Infrastructure quality
Economic aspects	Product market	GCR product market score
	Labor market	GCR labor market score
	Financial system	GCR financial system score
	Freedom of investment	Economic Freedom Index
	International trade	WTO membership
	Income inequality	Gini coefficient

Category	Subcategory	Indicators
	Wages	Minimum wage
	Default risk	Equity Risk Premium

Apart from natural resources, all indicators within the subcategories have the same weight. Only one indicator is selected in the "Net renewable potential" subcategory, since the potential with a higher cost threshold includes the potential at lower cost thresholds. The country assessment is based on average and threshold values as well as an evaluation based on factor analysis and a ranking using additional, qualitative criteria. The method is briefly explained below.

Average and threshold values

There are different ways to calculate averages and rankings when evaluating potential hydrogen supply countries. The categories can be assigned varying importance in the form of weighting, while subcategories with the same weighting form the respective category value.

When calculating a **simple total average**, each category is recorded with the same weighting and the indicators are calculated by simple addition. If a country is relatively weak in terms of its natural renewable resources, but has a high score in the other categories, it is shown as a potential exporter in the overall comparison. Since most industrialized countries have high values except for natural resources, this means that a large number of industrial nations are classified as potential exporters.

A **weighted total average** across categories makes it possible to account for the varying relevance of the categories. Weighting factors were therefore determined in a discursive process. The basis for the applied weighting factors was a survey of the expert team within the project on the one hand (see section 2.2.2), and a focus group workshop with regional development experts on the other hand (see section 2.2.1). A set of weighting factors for the categories was derived from the weightings assigned by these two groups, and these were then used to form a weighted average across all categories. Depending on the weighting, technical and natural resources could be assigned greater importance, for example.

Alternatively, instead of calculating a single average, a **threshold** value can be defined for each category, which the countries must meet in all five categories. [15] This means that a country is excluded if it is among the xx % (e.g. 30%) worst countries in the respective category; within the category, all the subcategories are weighted identically. Depending on the threshold value selected, this results in a short or longer list of countries. The remaining countries can then be ranked or clustered according to different criteria.

Factor analysis and multi-criteria assessment

Factor analysis is conducted to account for possible interdependence and correlation between categories and thus possible bias of the results. Factor analysis reveals whether there is a single influencing factor behind the selected criteria that could be used to account for a selection or development. This factor, which cannot be observed directly, is often referred to as a latent

[15] The value per category results as a simple average from the subcategories.

factor. One reason to suppose the existence of a latent factor is interaction between categories, such as between environmental aspects and social and institutional indicators, or between technology application and infrastructures and economic development. In addition, experts in the focus group workshop pointed out that policymakers could use the relevant technical or natural resources in some countries for the welfare of the population and that the effects are then likely to be seen in economic indicators. In other words, "wise policy making" and its consequences are reflected in the social and institutional and economic indicators and infrastructures. This interaction may imply a latent factor, which can be used to represent combined categories.

An additional analysis approach was also pursued, which differentiates between (short-), medium- and long-term imports for the purchasing countries or the potential exports of the supplier countries. From a long-term perspective, natural resources are the determining variable that cannot be influenced, while the other categories may change over time. In addition to the quantitative data, qualitative information is also decisive for these different time horizons, such as existing and proven partnerships, project planning and implementation as well as existing national strategies for possible qualification as a medium- or long-term hydrogen supplier country. These qualitative data are used as a signal for the fastest possible expansion of local hydrogen production and are therefore included in the analysis of medium-term potential exports.

2.1.5 Analysis tool

Due to the large number of countries and indicators considered and the associated complexity, it was necessary to develop an excel-based analysis tool to establish a ranking. The analysis tool is divided into two components: the front-end, which provides a graphic overview of the country ranking and enables this ranking to be determined based on different weightings. Second, the back-end, which records and then normalizes the data for the individual countries. The structure of the analysis tool and its two components are briefly described below.

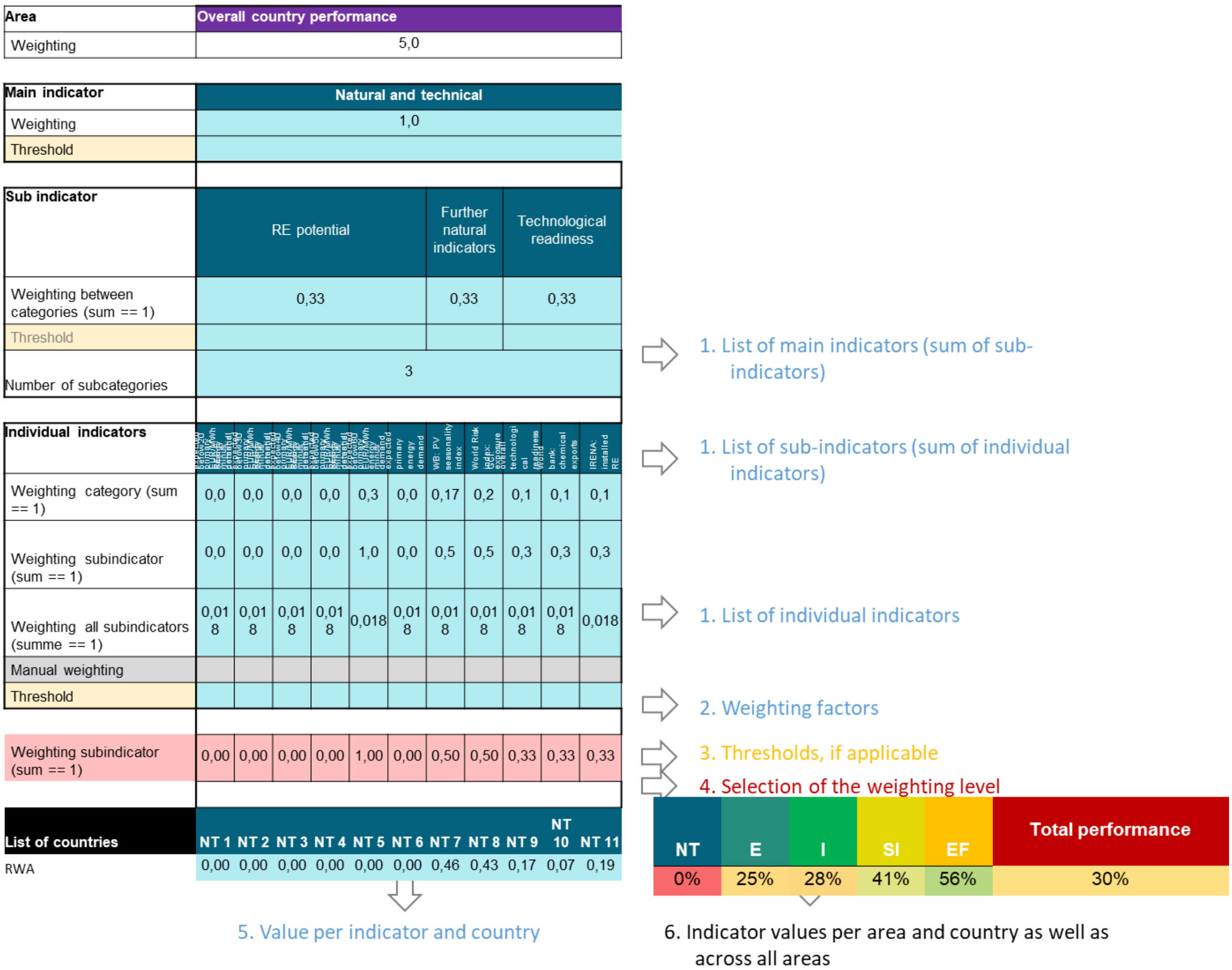
Country-specific data for the evaluation are stored in the back-end component of the analysis tool in the form of a comprehensive matrix. This also contains the corresponding specification of indicators for each country (if available). This component thus functions as an input mask and database. Since the indicators vary widely by type and scale (metric, ordinal, nominal), they have to be harmonized in a further step. The method used varies depending on the indicator. Dummy coding was used for dichotomous indicators (1/0, yes/no). For example, the specification of whether a country is a member of the WTO was coded with "1" and otherwise with "0".[16] For indicators that refer to a maximum potential, the share of the maximum value among countries was taken and transformed to an interval between 0 and 1. For metric variables, value ranges were defined or a linear transformation was performed to standardize them. Finally, the harmonized data together with the defined indicator weighting were used to calculate the country rankings.

Setting the indicator weightings and determining the country ranking is done in the front-end component of the analysis tool, which enables user interaction with the analysis tool. (1) The

16 An excerpt from the data sheet is shown in Appendix A1.4, which illustrates which dichotomous indicators were coded as 0 and 1.

previously defined indicators are separated in a tree structure from the main categories down to the individual indicators so that all levels of aggregation are displayed. (2) The analysis tool makes it possible to assign different or identical weights at all three levels. (3) allows threshold values to be set. Which weighting is ultimately used to rank the countries is selected under (4). There is also the possibility to enter manual values determined during the workshop, for example.

Figure 3: Excerpt from the front-end component of the analysis tool (see Appendix A.1.4 for an extended and comprehensive overview)



Finally, the result is determined for each country and each indicator using the defined weighting and the underlying country data stored in the database (5). In addition to this detailed presentation, the result is also displayed by category or as an overall performance (average total score) and can be used to select countries (6).

2.1.6 Qualitative criteria

Additional criteria were mentioned during the expert discussions on potential hydrogen export countries that could be relevant for a reliable supply of hydrogen. These include proven business relationships between Germany/EU and the export countries, especially agreements or partnerships. Expressions of interest in the potential export countries with regard to planning and implementing hydrogen production projects, as well as national hydrogen strategies and already initiated project plans are also indications of the export country's commitment to producing sustainable hydrogen.

In addition to sustainable hydrogen production and supply, geopolitical interests such as strengthening the economy, diversifying suppliers or supply countries play an important role in the final decision about a hydrogen partnership. Development policy objectives such as technology promotion and capacity building also influence potential partnerships. Another possible criterion is finding the right balance between industrialized nations, emerging and developing ones as well as between regions.

The following qualitative criteria were included in the analysis:

- Existing energy or hydrogen partnerships: Countries with which partnerships already exist for energy or hydrogen. The following publications were used as the sources: BMBF 2021, dena n. d., BMWi 2020 and 2021, BakerMcKenzie 2021.
- Existence of national hydrogen strategies: Countries that are in the process of implementing or have already developed strategies. Information about this was compiled from different sources: World Energy Council 2021, IPPR 2021, HySA Infrastructure n. d.
- Project planning: Hydrogen products being planned or realized. Compiled from various sources.
- Balanced by region: Regional classification was based on UN statistics (United Nations n. d.)
- Balanced by country income level: GDP per capita in PPP US$ of 2020. Source was the database of the International Monetary Fund, World Economic Outlook Database of October 2021. The division into three income classes was done based on the World Bank and was 1 for incomes up to US$ 10,000, 2 for incomes up to US$20,000 and 3 for incomes above US$20,000.
- Security and development policy interests of Germany and the EU.

2.2 Expert-based approach

2.2.1 Focus groups

Focus groups are a tried and tested method in the empirical social sciences. At their core, these are moderated group discussions based on a predetermined interview guideline. Focus group members are experts in a specific field. In a moderated group discussion, participants are not asked about factual information, but for their reasoned assessment of often complex subjects or expectations for the future. Via discussion and exchange with their peers in a safe setting, participants have the opportunity to modify or revise their spontaneous statements and assessments. Similar to a Delphi survey, this method achieves the best possible assessment in the context of a consolidated group opinion. Careful moderation ensures that individuals do not unduly dominate the discussion.

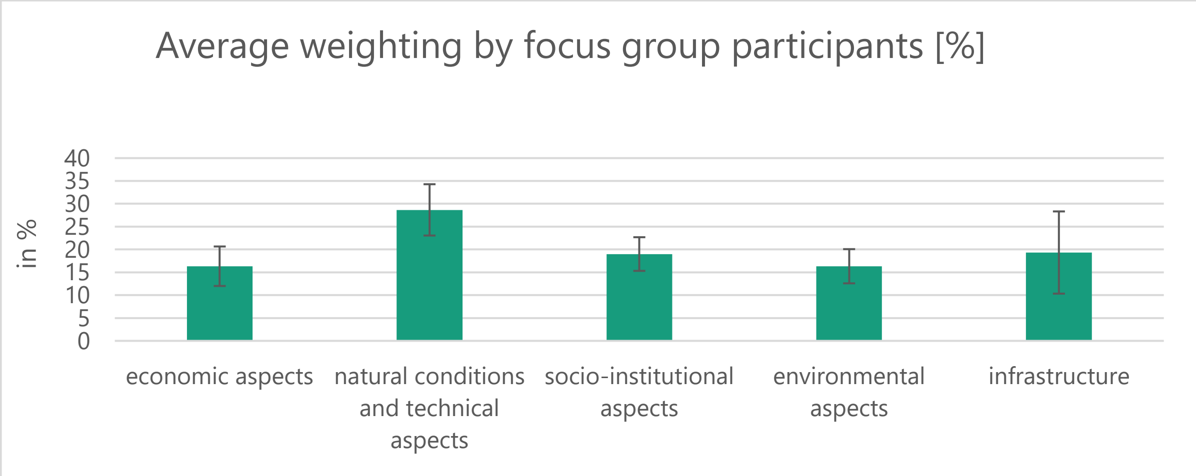
Focus groups are an appropriate method to explore the question of which countries are especially suited to producing green hydrogen in an international division of labor, as this is a complex topic encompassing multiple factors and not all its aspects are captured by internationally comparable indicators. Experts on four regions were invited to the workshop on January 28, 2022: Eastern Europe/Central Asia, Middle East and North Africa, Sub-Saharan Africa and South & Central America. Participants in the workshop work at the German Development Institute (Deutsches Institut für Entwicklungspolitik), the GIGA German Institute of Global and Area Studies in Hamburg, the German Institute for International and Security Affairs (Stiftung Wissenschaft und Politik (SWP)), the Nordic Africa Institute in Uppsala, Sweden, the Overseas Development Institute (ODI) in London and at universities in Germany, Turkey and Israel.

The focus group workshop was divided into two parts. The first addressed the question of indicator weighting, the second the selection of potential countries for exporting hydrogen. Both parts began by asking the participants questions. This was followed by a discussion of the assessment criteria and the countries, which was in turn followed by participants voting on the weighting factors or countries.

a) Weighting

As part of the focus group discussion, the 16 participants were first given an introduction to the project and to the specific question of the first part of the workshop. This included a presentation of the indicator-based approach as a whole and the categories and subcategories in particular. In a first step, and without discussing them, the participants entered (Software Mentimeter) the weighting factors they would assign to the individual categories and subcategories. This survey was followed by a discussion of the various (sub)categories, which concluded with a second survey round of weighting the categories. The weighting by the participants is shown in Figure 4.

Figure 4: Participant survey result of weighting the categories (n=16)



b) Countries

For each of the four regions, the participants were presented with lists of countries that had been named as potentially important producers of green hydrogen based on international comparative indicators, discussions within the HYPAT team, and feedback from the HYPAT advisory board. Based on four guiding questions about four particularly important topics, the participants were asked to comment on these lists and to rank the countries. The guiding questions revolved around water availability, governance capacities, starting points for national interconnections and knowledge transfer, as well as the possible integration of hydrogen production into long-term development strategies. In addition, the participants were asked to name and discuss additional potential countries for "their" region.

2.2.2 Discussion HYPAT advisory board and project team

As discussed in Chapter 2, in order to account for the varying relevance of the categories when assessing countries as potential hydrogen suppliers, weighting factors were also discussed by the project team and a survey was then conduced in the same team. Participants had a total of 100 points to distribute among the five categories. 26 members of the project team took part in this online survey and submitted their weighting of the individual categories. These results differed only slightly from the weighting of the focus group in terms of the significance accorded to environmental aspects.

In addition, the approach used (chapter 2) and the first results of the analysis were presented to the project team and the advisory board. The advisory board then also discussed the initial country selection. The board suggested that existing studies of potential hydrogen export countries should be researched and reviewed to determine whether the information contained in them was already sufficient for assessing their suitability as a hydrogen export country, so that these countries could therefore be excluded from further analysis in HYPAT. Analyses of Australia and Namibia were mentioned as examples of such studies. Important criteria for this research and literature analysis are the depth and comparability of the studies. It was also discussed which well-known studies refer to additional information and aspects that would provide additional value for HYPAT. These proposals were incorporated into the analysis within the qualitative criteria. Beyond this, there were no additional comments made about the suggested countries.

3 Results

3.1 Indicator-based results

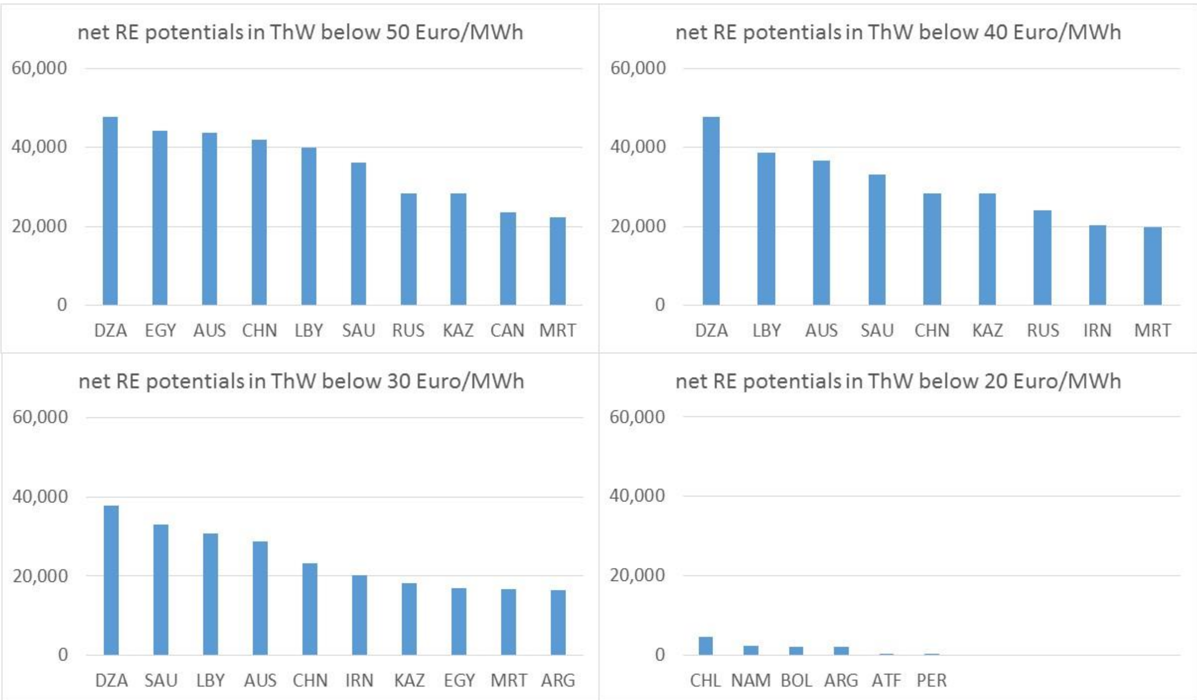
The following evaluation features those countries that were not excluded from the pool of countries after the minimum requirements (exclusion criteria) of section 2.1.2 had been met.

3.1.1 Results in the individual categories

Technical and natural resources

Algeria (DZA) has the largest net generation potential in 2050 with approximately 50 Petawatt hours/year (PWh/a) at a cost threshold of 50 Euro/MWh. In total, about 130 countries have a positive net generation potential, while the remaining countries show zero or, in some cases, negative potential because domestic demand is greater than their generation potential. Chile (CHL) has the best potential at the lowest price level of 20 Euro/MWh with about 5 PWh/a. Overall, the country ranking varies somewhat depending on the cost threshold, with a very low potential at the 20 Euro/MWh threshold compared to the other cost levels (Figure 5).

Figure 5: Net potentials of renewable electricity generation according to cost thresholds



Key: DZA: Algeria; SAU: Saudi Arabia; LBY: Libya; AUS: Australia; CHN: China; IRN: Iran; KAZ: Kazakhstan; EGY: Egypt; MRT: Mauritania; RUS: Russia; CAN: Canada; CHL: Chile; NAM: Namibia; BOL: Bolivia; ARG: Argentina; ATF: Tromelin; PER: Peru.

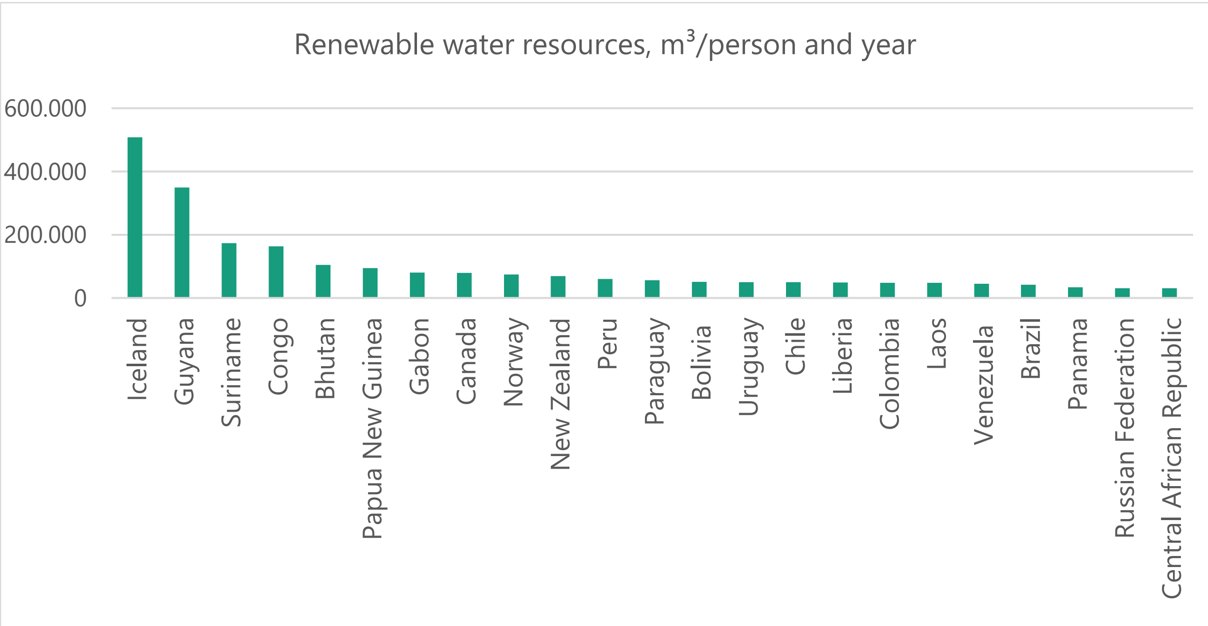
In a global hydrogen market, these more cost-favorable potentials will be exploited first, provided that any investment uncertainties are not too great and the necessary resources are available such as water and know-how. Therefore, more indicators are needed to estimate the technical, market, social and political uncertainties and thus the production and export potential.

If other indicators of natural resources and technical feasibility are taken into account (simple average of the category natural and technical resources), then more industrialized countries such as China, Australia and Saudi Arabia nudge ahead of Algeria and Egypt, followed by Russia, Canada, Argentina, Iran, USA, and Kazakhstan.

Environmental indicators

In the environmental category (based on a simple average of the subcategories), the industrialized countries do particularly well; Luxembourg leads the way followed by the Netherlands, Australia, the UK, Germany, Belgium, and the USA. Taking a closer look at the individual subcategories such as the available water resources, countries such as Iceland head the top 10 list (see Figure 6). In terms of waste management, on the other hand, countries such as Colombia & the Netherlands, Denmark & Sweden, Singapore, Switzerland, Mauritius, Germany, Finland, Norway & Belgium, Austria, South Korea & Malta edge into the top 10. However, with regard to renewable resources, it becomes clear that neither environmental management nor water availability are sufficient on their own as indicators of a country's suitability as a potential hydrogen producer. Instead, as high an overall standard as possible is desirable across all the environmental areas and categories listed in chapter 2 (section "Environmental indicators").

Figure 6: Water resources available in m³/capita and year (2017)



Note: UN-Water SDG 6 Data Portal, "renewable water resources: total" and population figures in 2017 taken from UN data.

Social and institutional indicators

In the overall assessment of the social and institutional criteria, industrialized countries also come out top of the list, with Switzerland in first place, followed by Denmark, Germany, Finland, Great Britain, Austria, France, and Australia. With regard to the promotion of renewable energies, industrialized countries such as Germany, Denmark, Great Britain, and Switzerland also dominate the top 10. The ranking according to the overall social and institutional performance, the subcategories general institutional environment, energy policy and knowledge generation/dissemination/standardization are shown in Appendix A.2.1.

Infrastructure

A list of the top 20 countries for each category and subcategory was compiled to identify the most advanced and suitable countries for hydrogen infrastructure integration and deployment. Countries with a surface area under 10,000 km^2 (Appendix A.1.2 Appendix A) or potential net renewable energy importers (Japan, South Korea, Thailand, Vietnam, Indonesia, Malaysia, India, and the EU) are not included in this list.

For the logistics category, five different indicators were evaluated for each country. If a country is listed in the top 20 for all indicators in the logistics subcategory, it receives five points in the logistics category.

Figure 7 provides an overview of all the categories of the infrastructure indicator. The bar chart shows the total number of times that countries are named among the top 20 countries for all sub-indicators. The lists of the top 20 countries for each indicator can be found in Appendix B-F (in Appendix A.1.2).

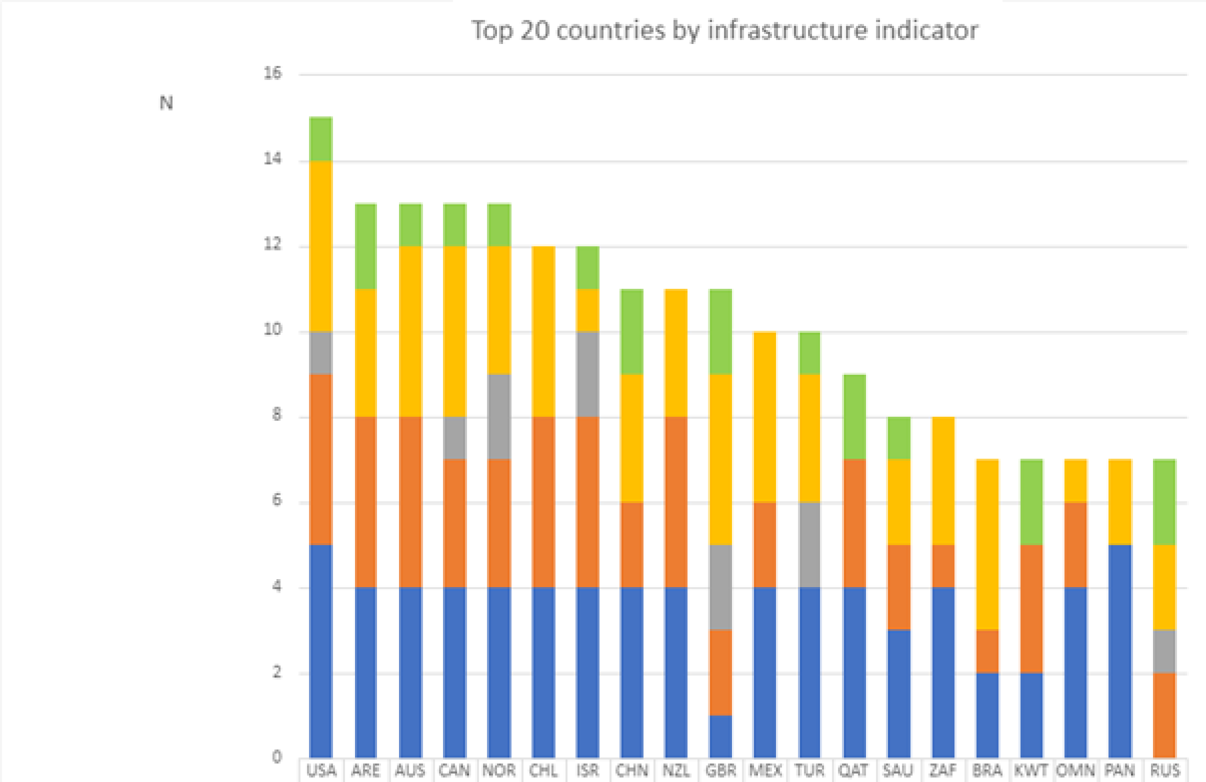
The USA is listed 15 times out of a possible 18. It offers the best potential for hydrogen infrastructure deployment. Under the subcategories of ports, utilities and logistics, the U.S. is in the top 20. The only times the U.S. was not included in the top 20 were for transportation via pipeline and transport distance to Germany.

The United Arab Emirates, Australia, Canada and Norway are each listed 13 out of 18 times among the top 20 countries and stand out for their well to very well developed logistical facilities, supply services and existing seaport infrastructure.

Chile and Israel are each listed 12 out of 18 times. These countries also stand out for their well to very well developed logistical facilities and supply services. While Chile has an excellent port infrastructure, Israel has a short transport distance to Germany.

China, New Zealand and the UK are next in the ranking, listed 11 out of 18 times, closely followed by Mexico and Turkey, which are listed 10 out of 18 times. Qatar features on half the possible listings. Brazil, Kuwait, Oman, Panama and Russia have less than half the listings and come last with 8 out of a possible 18 listings.

Figure 7: Summary of the top 20 countries listed in this area per subcategory



	USA	ARE	AUS	CAN	NOR	CHL	ISR	CHN	NZL	GBR	MEX	TUR	QAT	SAU	ZAF	BRA	KWT	OMN	PAN	RUS
Pipelines	1	2	1	1	1	0	1	2	0	2	0	1	2	1	0	0	2	0	0	2
Sea ports	4	3	4	4	3	4	1	3	3	4	4	3	0	2	3	4	0	1	2	2
Transport distances to Germany	1	0	0	1	2	0	2	0	0	2	0	2	0	0	0	0	0	0	0	1
Utility services	4	4	4	3	3	4	4	2	4	2	2	0	3	2	1	1	3	2	0	2
Logistics	5	4	4	4	4	4	4	4	4	1	4	4	4	3	4	2	2	4	5	0

Source: Fraunhofer IEG's own representation; Note: Maximum number of listings per subcategory: transportation via pipeline (3), seaports (4), transport distance to Germany (2), utilities (4), logistics (5). The maximum number of possible listings across all subcategories is 18. ARE- Argentina, AUS-Australia, CAN-Canada, NOR-Norway, CHL-Chile, ISR-Israel, CHN-China, NZL-New Zealand, GBR-Great Britain, MEX-Mexico, TUR-Turkey, QAT-Qatar, SAU-Saudi Arabia, ZAF-South Africa, BRA-Brazil, KWT-Kuwait, OMN-Oman, PAN-Panama, RUS-Russia.

Economic framework conditions

As expected, industrialized countries and developed economies perform best across all indicators of the economic-financial aspect. The Netherlands, Luxembourg, Denmark, Finland, Sweden, the United Kingdom, Singapore, New Zealand, Australia, the United States, Germany and Switzerland are in the top 20 for at least five of the seven indicators. Austria, Canada, Norway, Belgium, Japan, Malaysia, Ireland, Iceland and France are also frequently among the "best" countries for a single indicator ranking. The indicator values of the leading countries are largely similar. For example, the estimated equity risk premium for the "best" 13 countries is the same (4.72%). Nevertheless, when looking at the entire sample, there is still a wide range of individual indicator values (see, for example, the detailed overview in Table 3).

Similarly, the aggregated economic criteria indicator has industrialized countries in first place, with European countries occupying the top 10 positions.

3.1.2 Multi-criteria analysis

Ranking based on average values and threshold values

The indicators per category are expressed as an aggregated value per category, which includes each subcategory equally. An aggregated overall indicator represents the overall performance of a country and is derived from the indicators of the individual categories. The following evaluation is based on the method described in section 2.1.4 for a simple ranking.

A ranking based on a simple average (each category has the same weight) results in a list of countries composed exclusively of industrialized countries such as Australia, Finland, Spain, Ireland, etc. A ranking that takes into account the weighting factors (section 2.1.4) also shows a strong dominance of industrialized countries, despite the higher weight assigned to the natural and technical indicators. Australia, Canada and Spain make up the top three countries, China is in eighth place, and Egypt and the United Arab Emirates are ranked 13 and 14. (see Appendix A.2.1).

A list of around 40 countries results if a threshold value of 30% is applied, i.e., countries are excluded that are ranked in the bottom 30% of the respective category. The countries in this list can be sorted by any criteria. If a renewable potential below 50 Euro/MWh is used for the ranking, the top 10 countries include Algeria, Egypt, Australia, China, Saudi Arabia, Russia, Kazakhstan, Canada, Iran, and Argentina (see A.2.3). On the other hand, if the cost threshold of 20 Euro/MWh is used as a ranking criterion, then only Chile, Argentina, and Peru are left.

If 40% of the worst countries per category are excluded, the list of countries shortens significantly, and includes Australia, Russia, Canada, USA, Chile, Brazil, South Africa, Mexico, and Tunisia among the top 10 countries. Applying a cost threshold of less than 20 Euro/MWh as a ranking criterion reduces the list to Chile and Argentina.

Medium and long-term perspectives

The correlation and factor analysis suggest that there are significant interdependencies between categories. For example, there is a strong and significant correlation between infrastructures and the environmental, social and institutional, and economic criteria (Table 6). The results of the factor analysis show that these categories have the same factor loading, i.e., there is a single underlying factor behind these categories. Thus, these categories can be included in the analysis as an aggregate (simple average).

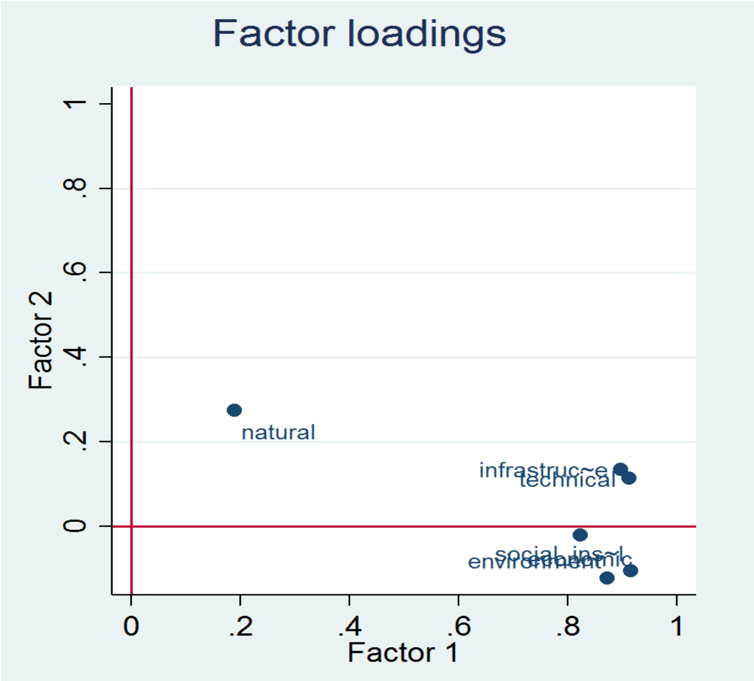
Table 6: Correlation between indicators at the category level (n=183)

	natura~h	enviro~t	infras~e	social~l	economic
natural_tech	1.0000				
	183				
environment	0.0399	1.0000			
	0.5916				
	183	183			
infrastruc~e	0.1732	0.7992	1.0000		
	0.0190	0.0000			
	183	183	183		
social_ins~l	0.0986	0.8200	0.8151	1.0000	
	0.1841	0.0000	0.0000		
	183	183	183	183	
economic	0.1888	0.6915	0.7224	0.7463	1.0000
	0.0105	0.0000	0.0000	0.0000	
	183	183	183	183	183

Source: Fraunhofer ISI's own analysis; supplement: analysis at category level. The categories are shown on the horizontal and vertical axes; the indicated values show the correlation value, the significance, the number (reading from top to bottom)

Due to the changing importance of the security of energy supply, a medium-term as well as a long-term perspective with a time horizon until 2050 was taken. The current technical, economic, social and institutional factors and environmental aspects may change over a long-term time horizon, whereas natural potentials are expected to change less. From a medium-term perspective, the study shows which countries could become potential hydrogen suppliers relatively quickly due to their technical and structural conditions, partnerships, and strategies. A long-term analysis, on the other hand, considers the technical and natural potential in a differentiated manner, i.e. two categories are created out of one category. Five of these categories are represented by an aggregated factor (average value). The factor analysis using these six categories (natural, technical, economic, social and institutional, infrastructure, environment) underpins this differentiation (see Figure 8).

Figure 8: Results of the factor analysis



Source: own calculation, Fraunhofer ISI

Overall indicator from a medium-term perspective

In order to maintain a reliable supply of imported hydrogen in the medium term, the technical and natural conditions and the aggregated factors of the other categories are represented as an average value. Here, the technical-natural conditions and the aggregated factors are taken into account equally. This approach is based on the results of the factor analysis and the rationale that existing structures, technologies, relationships and partnerships as well as national strategies are important for a rapid development of production. The top 30 countries in the ranking are then presented and evaluated based on planned or ongoing hydrogen projects, energy and hydrogen partnerships with Germany, and the existence of national hydrogen strategies. Those countries that meet all the criteria in the above areas can be rated as potentially good export countries in the medium term (rating 1). These are Australia, Portugal, China, Saudi Arabia, Canada, and Egypt. At the next level (rating 2), i.e., the countries that fulfil two of the qualitative criteria, are USA, Brazil, Chile, Algeria, Russia and Spain. Chile and Argentina are among the countries with the most favorable potentials, but Argentina falls into the fourth rating bracket (Table 7).

Table 7: Overview of potential export countries from a medium-term perspective

Country	Australia	New Zealand	Russian Federation	Poland	Romania	Ukraine	Sweden	Ireland	Finland	Lithuania	Latvia	Spain	Portugal	Greece	Kazakhstan
ranking natural-technical and aggregated factors	1	19	7	13	27	28	9	10	18	29	30	5	11	15	14
hydrogen projects	1				3							2	3		3
energy or hydrogen partnership	1		1			1							1		1
national hydrogen strategy	1	1	1	1			1		1			1	1		
	1	3	2	3	3	3	3	4	3	4	4	2	1	4	2
Region	Australia and New Zealand		Eastern Europe				Northern Europe					Southern Europe			Central Asia

Country	China	Iran	Saudi Arabia	United Arab Emirates	Turkey	Mexico	Canada	United States	Brazil	Chile	Argentina	Columbia	Egypt	Algeria	South Africa
ranking natural-technical and aggregated factors	3	25	8	17	22	23	2	4	16	20	21	26	6	12	24
hydrogen projects	2		3				3	2	3	3			3		
energy or hydrogen partnership	1	1	1	1	1	1	1	1	1	1			1	1	1
national hydrogen strategy	1		1				1			1		1	1	1	1
	1	3	1	3	3	3	1	2	2	2	4	3	1	2	2
Region	Eastern Asia	Southern Asia	Western Asia			Central America	Northern America		South America				Northern Africa		Southern Africa

Note: hydrogen projects: with 7 or more projects 1, between 4 and 6 projects 2, between 1-3 projects 3. Source: Fraunhofer ISI's own representation

Overall indicator from a long-term perspective

With a long-term horizon, countries have the potential to change significantly in terms of their technical competencies, political and institutional frameworks, infrastructures and their management of environmental resources. Therefore, from a long-term perspective, natural resources should be given more weight. For this purpose, the natural resources and conditions are recorded as a separate indicator and the technological development is combined with the other categories to form a single factor. This procedure is also supported by the factor analysis. An initial ranking was made based on the natural resources.

Subsequently, the top 30 countries within the "natural conditions" category were each sorted according to their low-cost potential and aggregated factors and assigned a rank. An average ranking was calculated based on this rank (rankings) per criterion, and countries with a very poor aggregated factor score (8 countries among the worst 30%) were removed from the assessment list. The highest ranked countries are Australia, Saudi Arabia, China, Iran, Kazakhstan, Chile, Argentina, Egypt, and Algeria. Other possible countries are Morocco, Namibia, South Africa, Mali, Mexico, Bolivia, Pakistan, Oman and Russia, followed by Botswana a long way behind. The selected countries are shown in Table 8.

Per capita income and the region were included in order to provide a good balance between the regions and the level of development of the countries. The existence of national hydrogen strategies and energy or hydrogen partnerships with Germany were also included in the long-term assessment.

Table 8: Overview of potential supplier countries from a long-term perspective

Country	Algeria	Egypt	Morocco	Namibia	South Africa	Botswana	Mali	Mexico	Canada	United States	Argentina	Brazil	Bolivia	Peru	Chile	Kazakhstan	China	Mongolia	Iran	Pakistan	Saudi Arabia	Oman	Russian Federation	Australia
ranking natural potential at 20 Euro/MWh				2							3		2	4	1									
ranking natural potential at 30 Euro/MWh	1	9	23	21	19	26	12	22	27	20	11	15	28	29	17	7	5	13	6	14	2	18	28	4
ranking natural conditions	1	2	26	18	23	28	15	27	10	16	13	17	22	30	24	8	5	14	12	20	7	21	9	3
ranking of aggregated factors	12	14	11	21	6	22	24	5	2	3	13	7	23	15	4	16	8	20	17	18	10	19	9	1
average rank	5	8	20	16	16	25	17	18	13	13	10	13	19	20	12	10	6	16	12	17	6	19	15	3
energy or hydrogen partnership	1	1	1	1	1		1	1	1	1		1			1	1	1		1		1		1	1
national hydrogen strategy	1	1	1	1	1				1						1		1				1	1	1	1
income level (1 = low; 2 = middle; 3 = high)	2	2	1	1	2	2	1	1	3	3	3	2	1	2	3	3	2	2	2	1	3	3	3	3
Region	Northern Africa			Southern Africa			Western Africa	Central America	Northern America		South America					Central Asia	Eastern Asia		Southern Asia		Western Asia		Eastern Europe	Australia and New Zealand

Source: Fraunhofer ISI's own representation

3.2 Results of the focus groups

During the focus group workshop at the end of January 2022, four regional lists of potential export countries of green hydrogen were discussed and ranked. Furthermore, the participants were asked to name other countries in their particular region of expertise. For the Eastern Europe/Central Asia region, Turkey was cited as particularly promising, in part because other countries in the region with high potential for hydrogen production (Kazakhstan and Ukraine) are currently unlikely to be considered. For Sub-Saharan Africa, Ghana, Namibia and South Africa were mentioned, and for the Middle East/North African region, Algeria, South & Central Africa and the United Arab Emirates were named. Argentina, Brazil and Costa Rica were also named as countries that are particularly suitable for hydrogen production in South America, with Chile also regarded as generally suitable.

3.3 Political priorities and supply relationships

How reliable the supplier country is or how certain the commodity supply plays a major role in the selection of potential suppliers. In addition, geopolitical interests and development policy goals may be of influence when setting up supply relationships, as such relationships will support them. Integrating them into a new, future-oriented energy strategy can support societal transformation, especially if new, sustainable employment opportunities and incentives for higher education and training are created. In conjunction with measures aimed at development cooperation, a contribution can be made to reducing the causes of migration and to the political stabilization of partner countries and developing regions. Hydrogen could be used to strengthen the link between economic and political priorities (Bossuyt et al. 2020). The potential supplier countries are analyzed below with regard to the following three aspects:

- Reliability in terms of the security of supply
- Development policy objectives
- Security policy interests

Assessing all three aspects involves a considerable degree of uncertainty, especially when it comes to medium to long-term evaluations. With existing methods, long-term forecasts of the stability of political systems are possible only to a limited extent. Development and security policy priorities can also change within a relatively short period of time. In the interests of risk spreading the risk, it can therefore make sense to ensure a broad regional coverage when selecting supplier countries.

3.3.1 Reliability

Current foreign and domestic conflicts

In order to assess the stability and reliability of potential supplier countries, it is necessary to first assess the risks of domestic political disruptions and conflicts that may have an impact on the ability or willingness to supply hydrogen. State involvement in internal and external conflicts can be regarded as a key proxy for stability and accountability. These can directly affect the reliability of countries as suppliers or indirectly lead to states becoming involved in conflicts that place a strain on trade relations (cf. the current situation with the Russian invasion of Ukraine).

With a view to medium-term stability and reliability, the Global Peace Index (GPI) offers a useful approach to assessment. This meta-index, developed by the Institute for Economics & Peace, maps the extent of peace in various countries. The index takes into account a total of 23 indicators for domestic and foreign conflicts in various dimensions (including domestic and international conflicts, social stability, militarization) and therefore provides an indication of the risk of conflict that could potentially affect the reliability of a country as a trading partner. Based on the Global Peace Index 2020 (Institute for Economics & Peace 2020), the assessment of the countries in the medium term is shown in Table 9.

In addition to EU member states and other Western democracies such as New Zealand, Australia and Canada,[17] various South American states (Argentina, Chile, Costa Rica), African states (Ghana, South Africa) and Asian states (United Arab Emirates, Kazakhstan) are also included on this basis. There are considerable differences in the assessment, particularly within the respective world regions, with individual countries deviating significantly from the regional average. In this respect, Russia, Ukraine, Turkey, Iran, Colombia, Mexico, Egypt, Brazil and Saudi Arabia currently all appear to be less suitable.

17 The U.S. appears to be a unique case that must be interpreted differently because of its global role.

Table 9: Global Peace Index (GPI)

Country	Global Peace Index (2020)	Relative rank Global Peace Index	Absolute rank Global Peace Index
Oceania			
New Zealand	1.243	2	3
Australia	1.435	6	14
America			
Canada	1.331	3	7
Costa Rica	1.719	13	38
Chile	1.831	15	50
Argentina	1.970	19	71
United States	2.27	21	120
Brazil	2.409	25	128
Mexico	2.571	27	138
Columbia	2.632	28	140
Africa			
Ghana	1.762	14	40
Algeria	2.290	22	122
South Africa	2.33	23	123
Egypt	2.410	26	129
Asia			
United Arab Emirates	1.901	17	64
China	2.070	20	94
Saudi Arabia	2.39	24	127
Iran	2.650	29	142
Kazakhstan	1.929	18	68
Europe			
Ukraine	2.88	30	148
Turkey	2.898	31	149
Russian Federation	3.001	32	154
Portugal	1.236	1	2
Ireland	1.379	4	11
Finland	1.391	5	13
Sweden	1.471	7	15
Romania	1.53	8	21
Lithuania	1.646	9	31
Spain	1.663	10	32
Poland	1.666	11	33
Latvia	1.689	12	35
Greece	1.872	16	56

Source: Institute for Economics & Peace 2020

Long-term preconditions for peace

This can be augmented by a longer-term view that looks at the prerequisites for peace at the levels of institutions, structures, and attitudes. The Positive Peace Index (PPI) describes these preconditions as the interplay of eight dimensions (well-functioning government, equitable distribution of resources, free flow of information, good relations with neighbors, high levels of human capital, acceptance of the rights of others, low levels of corruption, sound business environment), encompassing a total of 24 indicators, some of which are also important indicators for measuring socio-economic levels (cf. section 2.1.3). According to the Positive Peace Report 2022 (see Institute for Economics & Peace 2022, p. 60f), countries whose GPI index is significantly higher than their PPI values (so-called positive peace deficit) are particularly at risk of conflict. The absence of appropriate structural and institutional frameworks makes these countries more vulnerable to potential shocks and crises (cf. ibid. p. 4). High PPI values are therefore seen as a prerequisite for longer-term stability.

Based on this, Yemen, Chad, Libya seem particularly at risk, but Mauritania, Niger, Mali, Ethiopia and Pakistan are also potentially risky. In contrast, western democracies (Australia, Canada, USA) and various countries from all continents are possible contenders, e.g., Oman, Argentina, Chile, Brazil, Mexico, Botswana, Namibia, Mongolia, Kazakhstan, China, South Africa, Saudi Arabia, Algeria or Morocco (see Table 10).

Table 10: Positive Peace Index (PPI)

Country	Positive Peace Index 2020	Rel. rank Positive Peace Index	Absolute rank Positive Peace Index
Oceania			
Australia	1.394	2	8
America			
Canada	1.366	1	7
United States	1.95	3	24
Chile	2.147	4	32
Argentina	2.632	5	45
Brazil	2.98	10	63
Mexico	3.123	15	76
Bolivia	3.277	18	93
Africa			
Botswana	2.686	6	48
South Africa	2.925	9	58
Namibia	3.081	12	69
Morocco	3.177	17	80
Algeria	3.386	19	96
Egypt	3.596	21	114
Ethiopia	3.737	23	131
Niger	3.766	24	133
Mali	3.844	25	137
Mauritania	3.876	26	139
Libya	4.097	28	152
Chad	4.374	29	159
Asia			
Oman	2.866	7	55
Mongolia	2.922	8	57
China	3.004	11	66
Saudi Arabia	3.158	16	79
Iran	3.567	20	108
Pakistan	3.736	22	130
Yemen	4.542	30	161
Russian Federation	3.088	13	71
Kazakhstan	3.118	14	75
Turkmenistan	3.889	27	140

Source: Institute for Economics & Peace 2022

3.3.2 Development policy goals and priorities

In addition to the criteria for stability and reliability, it is important to examine to what extent the selection of H_2 countries is in line with development policy priorities. There is no doubt that long-term bilateral or multilateral cooperation can have an important stabilizing and confidence-building effect for partner countries. For many countries, the prospect of access to the European market provides a strong incentive to undertake reforms (Borchert et al. 2021). Especially for weak economies and countries in political transition, hydrogen partnerships can be an important building block for economic, social, environmental and political development. In order to support the alignment with the development policy objectives, it makes sense to explore the possibility of hydrogen partnerships with countries with which Germany has already agreed on long-term development policy cooperation. The main strategy used as a basis for this is the *BMZ 2030 reform concept* (BMZ 2020), which was adopted in 2020 and includes a total of 61 partner countries. Of these countries, several have relevant potential for hydrogen production: bilateral partnerships exist with Egypt, Algeria, Mali, Namibia and Pakistan. In 2019, the German government also agreed a so-called reform partnership with Morocco, which is aimed at particularly close and long-term cooperation. Germany also maintains several so-called transformation partnerships to support political and economic transformation processes in the EU's neighboring countries. Of the seven partner countries in this category, only Ukraine has any noteworthy potential in the hydrogen sector. Finally, supplier countries with which Germany cooperates within the framework of European or multilateral cooperation can also be considered. Among these countries, Bolivia, Kazakhstan and Mongolia have a significant potential for the supply of hydrogen.

3.3.3 Security policy perspective

Finally, the importance of potential hydrogen supplier countries in terms of security policy must also be taken into account. Cooperation can help build trust, promote political dialogue and limit the influence of geopolitical competitors such as Russia and China (Stueber 2022). The German government is currently revising its national security strategy, which is to be published in summer 2022 (Auswärtiges Amt 2022). In all likelihood, however, this will be closely aligned with the European security strategy from 2016 and the recently presented security policy compass (Council of the EU 2022). These documents focus in particular on the countries in Europe's southern and eastern neighborhood. Several North African states have been struggling with political instability and extremism for some time. At the same time, China, Russia and other states are trying to expand their influence there. European cooperation in the hydrogen sector could have a bonding and stabilizing effect here. Both Algeria and Morocco as well as Egypt are potential candidates here. In the eastern neighborhood, as already mentioned above, only Ukraine has relevant potential as a hydrogen supplier. Even if Ukraine is not likely to be considered as a supplier country for hydrogen in the short term, a partnership could well be appropriate in the medium to long term from the perspective of security policy.

4 Summary and conclusions

For the evaluation of a country as a potential hydrogen exporter, a set of criteria consisting of quantitative as well as qualitative criteria was applied. The quantitative analysis includes natural, technical, economic, social and institutional factors as well as environmental aspects and infrastructure. The qualitative criteria are based on existing energy partnerships, national hydrogen strategies and project planning.

The multi-criteria analysis using weighting factors for the various categories identified industrialized countries in particular as potential hydrogen suppliers. However, a factor analysis revealed that there is a latent factor behind the last four to five categories.

Therefore, the environmental, infrastructure, economic and social and institutional criteria were summarized in an aggregated factor (factor analysis) within a medium-term horizon. These criteria were supplemented by qualitative criteria such as the existence of national hydrogen strategies and projects as well as energy partnerships. These indicate the possibility of the country developing rapidly into hydrogen suppliers. The subsequent evaluation, which considers the technical and natural conditions, leads to a selection of countries that could ultimately supply hydrogen relatively quickly due to their high scores on the aggregated factors and the qualitative criteria: Australia, Portugal, China, Saudi Arabia, Canada, Egypt, USA, Brazil, Chile, Algeria, Russia, and Spain.

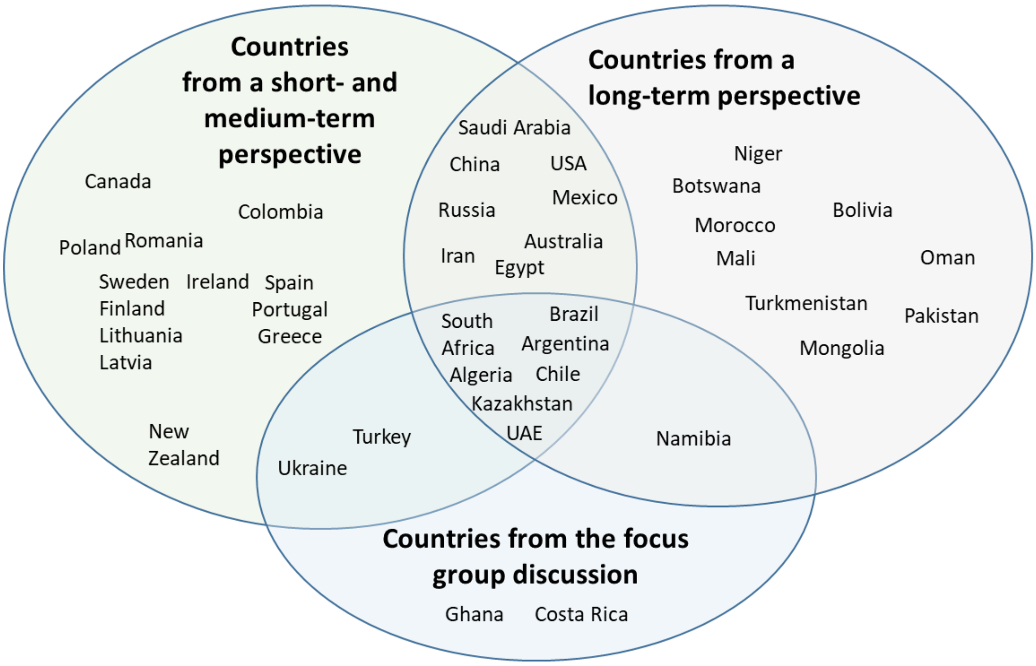
If the basis is a long-term time horizon, the natural resources should be weighted more heavily. Thus, countries with cost-efficient and good natural resources are especially qualified. However, they must also meet a minimum threshold for the aggregated factor: Australia, Saudi Arabia, China, Iran, Kazakhstan, Chile, Argentina, Egypt, Algeria, Morocco, Namibia, South Africa, Mali, Mexico, Bolivia, Pakistan, Oman and Russia, and by some margin Botswana.

The expert-based approach identified additional countries that were left out of the indicator-based analysis. These are Turkey, Ghana and Costa Rica.

Combining the various perspectives reveals a number of intersections as shown below in Figure 9. Some countries, such as Brazil, Chile, Argentina, as well as Algeria, South Africa, United Arab Emirates and Kazakhstan, are identified as possible supplier countries from all three perspectives.

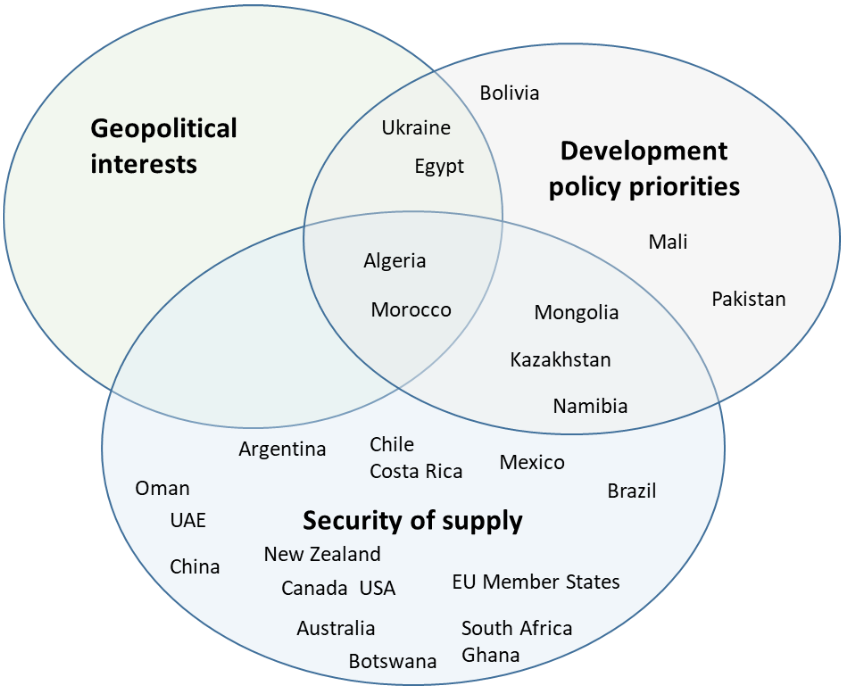
In view of the latest developments in Eastern Europe, it is advisable to include additional criteria regarding potential hydrogen export countries. These include supply, development and geopolitical priorities. Figure 10 shows how these political interests were added to the selection based on indicators and focus groups. It shows that the MENA region in particular could be a possible region for hydrogen supplies to Germany and the EU.

Figure 9: Supplier countries based on the indicators and focus group discussion



Source: own representation, Fraunhofer ISI

Figure 10: Supplier countries taking into account political priorities



Source: Fraunhofer ISI's own illustration

The final selection chosen for in-depth analyses should be based on the requirements of the respective analyses and ensure a broad coverage by region and level of development of the countries, while simultaneously considering which countries have already been identified as exporting countries and studied in detail.

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Appendix

A.1 Supplementary information on the method

A.1.1 Minimum requirement: Countries/territories with net RE potential of less than 100 TWh with costs of more than 70 Euro/MWh in 2050

Country	ISO3	Country	ISO3	Country	ISO3	Country	ISO3
Abyei	XU	**Cyprus**	CYP	**Jersey**	JEY	**Saint Kitts and Nevis**	KNA
Albania	ALB	**Czechia, Czech Republic**	CZE	**Kiribati**	KIR	**Saint Lucia**	LCA
American Samoa	ASM	**Dominica**	DMA	**Korea, Republic of (South Korea)**	KOR	**Saint Pierre and Miquelon**	SPM
Andorra	AND	**El Salvador**	SLV	**Lebanon**	LBN	**Saint Vincent and The Grenadines**	VCT
Anguilla	AIA	**Equatorial Guinea**	GNQ	**Liechtenstein**	LIE	**Samoa**	WSM
Antigua and Barbuda	ATG	**Estonia**	EST	**Luxembourg**	LUX	**San Marino**	SMR
Armenia	ARM	**Eswatini**	SWZ	**Malaysia**	MYS	**São Tomé and Príncipe**	STP
Aruba	ABW	**Faroes**	FRO	**Maldives**	MDV	**Seychelles**	SYC
Arunachal Pradesh	XD	**Fiji**	FJI	**Malta**	MLT	**Singapore**	SGP
Austria	AUT	**French Guiana**	GUF	**Martinique**	MTQ	**Slovakia**	SVK
Bahamas	BHS	**French Polynesia**	PYF	**Mauritius**	MUS	**Slovenia**	SVN
Bahrain	BHR	**French Southern and Antarctic Lands**	ATF	**Mayotte**	MYT	**Solomon Islands**	SLB
Bangladesh	BGD	**Gambia**	GMB	**Micronesia**	FSM	**South Georgia and the South Sandwich Islands**	SGS
Barbados	BRB	**Germany**	DEU	**Moldova**	MDA	**Sri Lanka**	LKA
Belgium	BEL	**Grenada**	GRD	**Montenegro**	MNE	**Suriname**	SUR
Belize	BLZ	**Guadeloupe**	GLP	**Montserrat**	MSR	**Svalbard and Jan Mayen**	SJM
Bermuda	BMU	**Guam**	GUM	**Netherlands**	NLD	**Switzerland**	CHE
Bonaire, Sint Eustatius and Saba	BES	**Guatemala**	GTM	**New Caledonia**	NCL	**Thailand**	THA
Bosnia and Herzegovina	BIH	**Guernsey**	GGY	**Niue**	NIU	**Timor-Leste**	TLS
British Virgin Islands	VGB	**Guyana**	GUY	**Norfolk Island**	NFK	**Tonga**	TON
Brunei Darussalam	BRN	**Haiti**	HTI	**North Macedonia**	MKD	**Trinidad and Tobago**	TTO
Burundi	BDI	**Hong Kong**	HKG	**Northern Mariana Islands**	MNP	**Turks and Caicos Islands**	TCA
Cape Verde	CPV	**Hungary**	HUN	**Palau**	PLW	**United Kingdom**	GBR
Cayman Islands	CYM	**Ilemi Triangle**	XG	**Palestine**	PSE	**Us Virgin Islands**	VIR
Chinese Taipei (Taiwan)	TWN	**India**	IND	**Panama**	PAN	**Vanuatu**	VUT
Christmas Island	CXR	**Indonesia**	IDN	**Philippines**	PHL	**Venezuela**	VEN

Country	ISO3	Country	ISO3	Country	ISO3	Country	ISO3
Comoros	COM	**Isle of Man**	IMN	**Puerto Rico**	PRI	**Vietnam**	VNM
Costa Rica	CRI	**Italy**	ITA	**Reunion**	REU	**Wallis and Futuna**	WLF
Croatia	HRV	**Jamaica**	JAM	**Rwanda**	RWA		
Curaçao	CUW	**Japan**	JPN	**Saint Helena, Ascension and Tristan Da Cunha**	SHN		

A.1.2 Indicator-based approach

Appendix A Infrastructure: List of excluded countries with a total area of less than 10,000 km^2. These countries were not included for the national airport density and ranking of the TOP 15 countries within the infrastructure subcategories.

Country	ISO 3 Code	ISO 2 Code	Area [km2]
San Marino	SMR	SM	61
Marshall Islands	MHL	MH	181
Kiribati	KIR	KI	186
Bahrain	BHR	BH	187
Dominica	DMA	DM	188
Tonga	TON	TO	189
Singapore	SGP	SG	190
Andorra	AND	AD	195
Palau	PLW	PW	197
Seychelles	SYC	SC	198
Barbados	BRB	BB	201
Grenada	GRD	GD	207
Malta	MLT	MT	208
Maldives	MDV	MV	209
Liechtenstein	LIE	LI	218
Tuvalu	TUV	TV	237
Nauru	NRU	NR	239
Monaco	MCO	MC	254
Saint Kitts and Nevis	KNA	KN	261
Saint Vincent and the Grenadines	VCT	VC	389
Antigua and Barbuda	ATG	AG	443
Saint Lucia	LCA	LC	616
Micronesia	FSM	FM	702
São Tomé and Príncipe	STP	ST	964
Mauritius	MUS	MU	2,220
Comoros	COM	KM	2,414
Luxembourg	LUX	LU	2,764

Country	ISO 3 Code	ISO 2 Code	Area [km2]
Samoa	WSM	WS	3,008
Cape Verde	CPV	CV	4,033
Trinidad and Tobago	TTO	TT	5,128
Brunei	BRN	BN	5,937
Republic of Cyprus	CYP	CY	9,420

Fehler! Keine gültige Verknüpfung.Fehler! Keine gültige Verknüpfung.Fehler! Keine gü-ltige Verknüpfung.

Appendix E Infrastructure: Ranking of the 20 best countries in the subcategory logistics[18]

Rank	Airport density	Customs	Infrastructure	International deliveries	Quality and competence in logistics
1	BHS	AUS	USA	ARE	NZL
2	CRI	USA	ARE	QAT	ARE
3	GTM	NZL	NZL	CHN	CAN
4	JAM	ARE	AUS	ZAF	USA
5	BLZ	CAN	CHN	USA	AUS
6	PRY	NOR	CAN	NOR	NOR
7	ISR	ISR	NOR	NZL	CHN
8	GBR	CHN	QAT	RWA	QAT
9	PAN	CHL	ISR	CAN	ISR
10	ECU	ZAF	TUR	PAN	PAN
11	FJI	QAT	CHL	OMN	CIV
12	USA	OMN	ZAF	CHL	ZAF
13	PNG	PAN	OMN	AUS	CHL
14	CUB	ECU	PAN	CIV	BRA
15	NIC	CIV	SAU	COL	OMN
16	LBN	MEX	KWT	MEX	TUR
17	URY	KGZ	BRA	TUR	MEX
18	DOM	KWT	CIV	ZMB	COL
19	COL	STP	MEX	SAU	SAU
20	PRK	TUR	EGY	ARG	BHR

18 Countries with a total area of less than 10,000 km^2 (Appendix A) or potential net importers of renewable energies (Japan, South Korea, Thailand, Vietnam, Indonesia, Malaysia, India, EU) are not included in this list.

Appendix F Infrastructure: Ranking the 20 best countries in the subcategory utilities[19]

Rank	Supply quality	Connection to electricity	Reliability of water supply	Waste disposal
1	BHR	CHL	ISR	NOR
2	CHL	ISR	AUS	AUS
3	ISR	CHN	CZE	NZL
4	CHN	KAZ	BHR	CAN
5	KAZ	AUS	CAN	USA
6	AUS	USA	USA	ISR
7	USA	QAT	CHL	LVA
8	BRN	GEO	NZL	ARE
9	QAT	NOR	ARE	CHL
10	LVA	NZL	URY	KWT
11	GEO	ARE	CRI	JOR
12	NOR	GBR	SAU	BLR
13	NZL	AZE	QAT	COL
14	ARE	RUS	OMN	MEX
15	GBR	JOR	RUS	CRI
16	SAU	UKR	KWT	ARM
17	ZAF	CAN	BRN	ARG
18	COL	ARM	ARG	BRA
19	OMN	KWT	NAM	BHR
20	AZE	MEX	AZE	ECU

[19] Countries with a total area of less than 10,000 km^2 (Appendix A) or potential net importers of renewable energies (Japan, South Korea, Thailand, Vietnam, Indonesia, Malaysia, India, EU) are not included in this list.

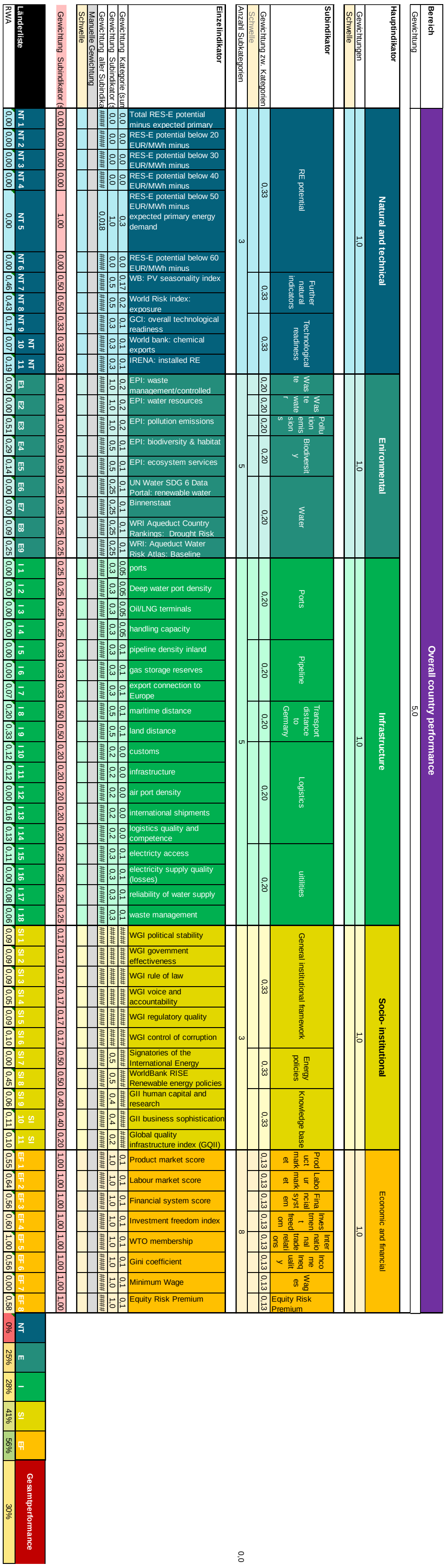
A.1.3 Expert-based approach

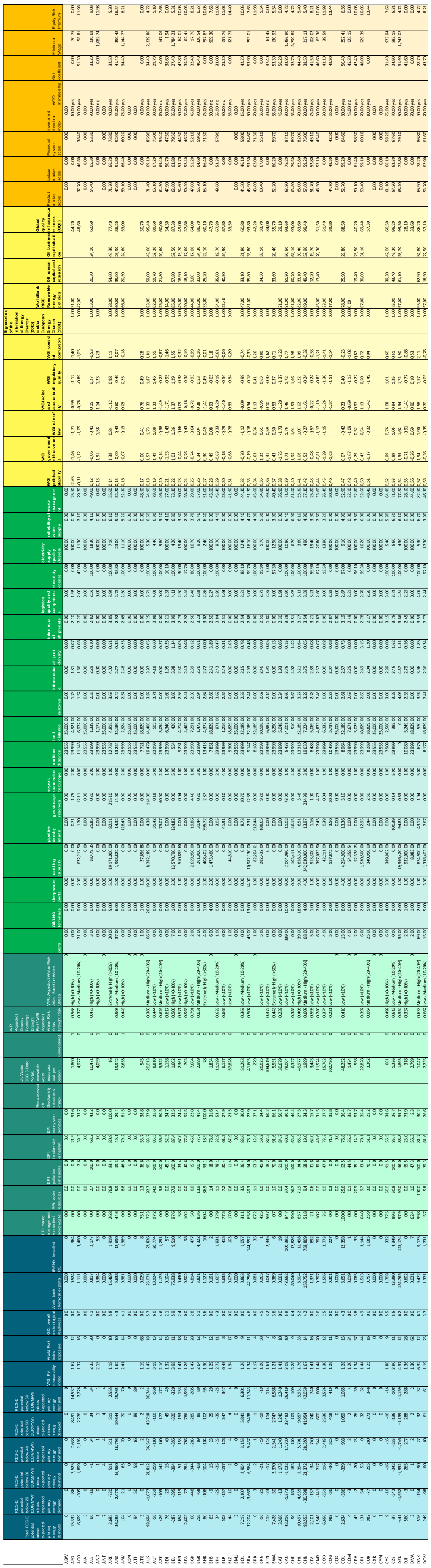
Figure 11: Weighting questions

Mentimeter: Questions for M1.1 and M1.2

1. please indicate how you would weight the following categories (total should be 100):
   - technical-natural resources,
   - economic aspects,
   - infrastruture,
   - socio-institutional
   - environmental aspects
2. please indicate how you would weight the following sub-categories of technical-natural resources (total should be 100)?
   - renewable energy potential
   - further natural indicators (natural risks, solar seasonality)
   - technological readiness (renewables, chemical industry, technology)
3. please indicate how you would weight the following sub-categories of environmental aspects (total should be 100)?
   - waste
   - waste water
   - emissions
   - biodiversity
   - water
4. please indicate how you would weight the following sub-categories of infrastructure (total should be 100):
   - ports
   - pipelines
   - transport distance to Germany
   - logistics
   - utilities
5. please indicate how you would weight the following sub-categories of socio-institutional aspects (total should be 100)?
   - general institutional framework (WGI indicators)
   - energy policies
   - knowledge base (standards, certifications, business sophistication, human capital & research)
6. please indicate how you would weight the following sub-categories of economic aspects (total should be 100)?
   - market
   - labour market
   - financial system
   - invesment freedom
   - international trade relations
   - income inequality
   - wages
   - equity risk

A.1.4 Structure of the analysis tool





A.2 Supplementary information

A.2.1 Ranking the social and institutional category

Country	Ranking overall category	Ranking institutional environment	Ranking energy policy	Ranking Knowledge
Switzerland	1	4	4	3
Denmark	2	2	2	9
Germany	3	10	1	7
Finland	4	1	8	5
Great Britain	5	13	3	11
Austria	6	16	13	12
France	7	19	5	13
Australia	8	12	11	17
Japan	9	17	16	15
Norway	10	3	19	20
Belgium	11	20	6	14
Ireland	12	15	9	19
Spain	13	25	7	24
Portugal	14	24	17	31
Hungary	15	44	10	29
Greece	16	42	14	33
Slovakia	17	37	12	45
Sweden	18	5	54	1
Bulgaria	19	49	15	44
Poland	20	38	28	32
Netherlands	21	7	58	6
Luxembourg	22	8	38	23
Romania	23	51	21	52
Turkey	24	78	18	40
Croatia	25	41	25	56
Canada	26	9	55	18
Iceland	27	11	39	28
Korea, Republic	28	27	56	2
Israel	29	22	59	10
Ukraine	30	90	24	37
Russian Federation	31	96	26	30
Singapore	32	14	79	8
Jordan	33	55	20	76
Slovenia	34	26	41	25
Estonia	35	18	40	39
United States	36	21	76	4
New Zealand	37	6	69	22
Kazakhstan	38	74	27	61
Cyprus	39	29	43	36
Armenia	40	62	23	90
Malta	41	32	45	34
Belarus	42	95	31	41
Lithuania	43	28	42	48
Bosnia-Herzegovina	44	86	29	64
Italy	45	35	50	26
Latvia	46	30	44	55
United Arab Emirates	47	39	61	21
Albania	48	71	30	86
North Macedonia	49	64	33	66
Chile	50	23	51	50
Lebanon	51	104	22	85
Georgia	52	34	46	67
Mongolia	53	70	37	75
India	54	53	48	43

Country	Ranking overall category	Ranking institutional environment	Ranking energy policy	Ranking Knowledge
China	55	85	67	16
South Africa	56	48	52	47
Montenegro	57	54	32	109
Brazil	58	66	57	35
Malaysia	59	45	84	27
Kirgizstan	60	93	35	89
Uruguay	61	31	66	65
Costa Rica	62	36	68	59
Azerbaijan	63	99	36	87
Columbia	64	57	62	57
Mexico	65	82	53	49
Tunisia	66	65	60	60
Moldova	67	81	47	80
Argentina	68	68	71	46
Serbia	69	67	70	54
Thailand	70	72	82	42
Ghana	71	52	64	96
Philippines	72	77	74	53
Tadzhikistan	73	111	34	107
Iran	74	108	49	62
Jamaica	75	46	80	79
Oman	76	56	85	63
Peru	77	63	95	51
Qatar	78	47	89	71
Morocco	79	80	65	77
Saudi Arabia	80	76	99	38
Vietnam	81	92	78	58
Egypt	82	100	63	72
Indonesia	83	59	86	70
Kenya	84	79	75	81
Panama	85	58	81	97
Dominican Republic	86	75	77	92
Sri Lanka	87	73	87	88
El Salvador	88	83	72	94
Equator	89	88	88	83
Bahrain	90	60	101	82
Bolivia	91	101	90	68
Kuwait	92	69	104	74
Mauritius	93	33	106	78
Tanzania	94	97	73	101
Brunei	95	43	108	69
Botswana	96	40	107	73
Benin	97	84	91	100
Algeria	98	105	92	84
Senegal	99	61	100	104
Honduras	100	94	94	95
Uganda	101	98	83	102
Pakistan	102	103	96	91

A.2.2 Weighted ranking

Weighting of the five main categories based on weighting factors derived from the workshop and survey.

Country	Ranking of weighted overall performance- indicator
Australia	1
Canada	2
Spain	3
United States	4
Ireland	5
Sweden	6
Portugal	7
China	8
Finland	9
Russian Federation	10
Greece	11
Poland	12
Egypt	13
United Arab Emirates	14
New Zealand	15
Saudi Arabia	16
Turkey	17
Chile	18
Iceland	19
Brazil	20
Kazakhstan	21
Algeria	22
Lithuania	23
Mexico	24
Romania	25
South Africa	26
Columbia	27
Latvia	28
Great Britain	29
Ukraine	30
Argentina	31
Denmark	32
Iran	33
France	34

A.2.3 Ranking with threshold value

Simple ranking with 30 % threshold:

Country	Ranking
Australia	1
China	2
Egypt	3
Algeria	4
Saudi Arabia	5
Canada	6
Russian Federation	7
United States	8
Kazakhstan	9
Argentina	10
Iran	11
Brazil	12
Spain	13
Mexico	14
South Africa	15
Chile	16
Portugal	17
Turkey	18
United Arab Emirates	19
Columbia	20
Morocco	21
New Zealand	22
Peru	23
Poland	24
Sweden	25
Romania	26
Ireland	27
Ukraine	28
Greece	29
Jordan	30
Ecuador	31
Uruguay	32
Georgia	33
Tunisia	34
Kuwait	35
Lithuania	36
Honduras	37
Latvia	38
Finland	39
Iceland	40