# Fair Green Hydrogen:

Chance or Chimera in Morocco, Niger and Senegal?

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## Contents

## Figures



## Tables

## List of abbreviations

| | |
|---|---|
| /a | Year |
| AU | African Union |
| BAU | Business-as-usual |
| bn | Billion |
| BMBF | *Bundesministerium für Bildung und Forschung* <Federal Ministry of Education and Research> |
| BMUV | *Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz <Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection>* |
| BMWK | *Bundesministerium für Wirtschaft und Klimaschutz* <Federal Ministry for Economic Affairs and Climate Action> |
| CAPEX | Capital expenditure |
| CAT | Climate Action Tracker |
| CCS | Carbon capture and storage |
| CCU | Carbon capture and use |
| CCUS | Carbon capture, use and storage |
| $CO_2$ | Carbon dioxide |
| ct | Euro cents |
| EC | European Commission |
| EIA | Environmental Impact Assessment |
| EJ | Etajoule |
| EU | European Union |
| EUR | Euro |
| FZ Jülich | Forschungszentrum Jülich |
| GHG | Greenhouse gases |
| Ghorfa | Arab-German Chamber of Commerce and Industry |
| GIZ | *Gesellschaft für Internationale Zusammenarbeit* <German Corporation for International Cooperation> |

| | |
|---|---|
| GW | Gigawatt |
| $H_2$ | Hydrogen |
| IEA | International Energy Agency |
| IRENA | International Renewable Energy Agency |
| KfW | *Kreditanstalt für Wiederaufbau* <German Development Bank> |
| kg | Kilogram |
| km | Kilometer |
| $km^2$ | Square kilometer |
| ktpa | Kilotonnes per annum (per year) |
| kWh | Kilowatt hours |
| l | Liter |
| LkSG | Germany's *Lieferkettensorgfaltspflichtengesetz* <Act on Corporate Due Diligence in Supply Chains> |
| LOHC | Liquid organic hydrogen carrier |
| $m^2$ | Square meter |
| $m^3$ | Cubic meter |
| MoU | Memorandum of Understanding |
| Mt | Megatons |
| MW | Megawatt |
| MWp | Megawatt peak |
| NWR | *Nationaler Wasserstoffrat* <National Hydrogen Council> |
| NWS | *Nationale Wasserstoffstrategie* <National Hydrogen Strategy> |
| NDC | Nationally Determined Contribution |
| NGO | Non-governmental organisation |
| OECD | Organisation for Economic Cooperation and Development |
| PEM | Proton exchange membrane |
| PtL | Power-to-Liquid |
| PtX | Power-to-X |
| SDGs | Sustainable Development Goals |

| | |
|---|---|
| SEA | Strategic Environmental Assessment |
| SOEC | Solid oxide electrolysis cells |
| t | Tons |
| TWh | Terawatt hour |
| $TW_{el}$ | Terawatt hours (electrical energy) |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USD | US-Dollar |
| WASCAL | West African Science Service Centre on Climate Change and Adapted Land Use |

# Conclusions of the Rosa Luxemburg Foundation

# based on the study "Fair Green Hydrogen: Chance or Chimera in Morocco, Niger and Senegal?" on the politics of hydrogen imports from the Global South

**Background**

Hydrogen (H2) and its secondary products will play an important role in the decarbonisation of economies in the future, particularly in four areas of application:

1. Cases where the much more efficient direct or battery-based use of electricity is impossible, or would only be possible at enormous costs (for example in air and sea transport, possibly in parts of heavy goods transport), hydrogen can be used in fuel cells or as hydrogen-based liquid or gaseous fuels, so-called synthetic fuels (synfuels).
2. Hydrogen will also serve as a long-term storage medium, especially to secure the energy supply via hydrogen gas turbines in periods of winter without wind and sun ("dark lull").
3. Hydrogen is needed to avoid greenhouse gases that are produced in industr due to material and not energy processes, e.g. in steel production. In addition, in high-temperature processes thermal uses of hydrogen and derived products are also possible alternatives to natural gas.
4. Hydrocarbon compounds produced from hydrogen and carbon will replace natural gas and crude oil as basic materials of the chemical industry (in addition to biogenic raw materials, which, however, have very limited potential).

If it is to be produced sustainably, - hydrogen used in these applications must be obtained from electrolysers using green electricity, combined with carbon where necessary. The latter must be produced in a climate-neutral way.

It is doubtful that hydrogen will become the "oil of the future", as many claim. While hydrogen as well as its by-products certainly have a high energy density and can therefore be used in a variety of ways and for a long time they have a serious disadvantage: the production of green hydrogen via an electrolysis process using green electricity is extremely energy- and cost-intensive - and this will hardly change in the foreseeable future. If hydrogen is not used in itspure form but as a liquid or gaseous compound with carbon, this require additional large amounts of energy. Green electricity, however, is a valuable commodity. Available land and the raw materials required are scarce and often conflict-laden - both in Germany and elsewhere.

Based on the numerical framework of the German Hydrogen Strategy, it can be estimated that the German government intends to import 70 to 80 percent of the hydrogen used in Germany in the medium and long term. Various actors in the economy and almost all the relevant research available assume that the required green hydrogen and all its chemical transformation products will largely come from abroad.

In the long term, the German government is focusing on North and West African countries as suppliers of green hydrogen. In the deserts of the Maghreb, large plants could produce hydrogen and synthetic fuels (PtX) from solar and wind power at low cost, according to the industry. An atlas charting the prudoction potential (Forschungszentrum Jülich, 2021) prepared for West Africa by the previous federal government, projects that up to 165,000 TWh of hydrogen could be produced in this region (BMBF, 2020b).

However, the problems associated with hydrogen imports have hardly been discussed so far. According to a meta-study by the Öko-Institut, the production of electricity-based materials like hydrogen can lead to higher CO2 emissions than the use of fossil alternatives as long as fossil generation capacities are still in the electricity system (Heinemann et al., 2019). Converting hydrogen production from natural gas hydrogenation to electrolysis, for example, therefore only makes sense when there is about 70 % green electricity in the grid. Electricity-based substitutes for diesel and natural gas will only be beneficial for the climate if green electricity attains a share of roughly 80% of electricity generation . According to the government's projections, such values are to be expected in Germany no earlier than 2030 (as of 2021: 42.6 % green electricity in gross electricity consumption).

Consequently, for Germany as an industrialised country, the usefulness of early large-scale hydrogen applications beyond pilot projects and a cleverly controlled growth path is questionable. PtX production for the transport sector at Germany's current green electricity quota would, to give an example, produce more greenhouse gases than the use of conventional fuels. Moreso, hydrogen production for Europe in the global South - without further accompanying measures - would impede decarbonisation in the Southern countries. In general, this would also be the case if investors of the Global North were to build and finance in the southern countries electrolysis plants as well as the green electricity plants needed for their operation. After all, it is highly likely that the most suitable natural sites (high wind speeds, solar radiation, water availability, good hydropower sites, etc.) and thus the cheapest sites would be used for this purpose, rendering them unavailable for domestic green electricity production.

### Terms of reference and key results of the study from Rosa Luxemburg Foundation's point of view

The present study by Arepo GmbH on behalf of the Rosa Luxemburg Foundation (RLS) examines how realistic hydrogen imports from the Global South are and which general conditions would have to exist in order to make them socially and ecologically just, using the example of the three countries: Senegal, Niger and Morocco. It concludes that imports from at least Senegal and Niger can hardly be expected in the foreseeable future: Previous imports are only viable if an extensive set of preconditions is met. In order to prevent a renewal of neo-colonial relations between producer and importing countries, strict conditions would have to apply for even for later imports. These include ruling out the possibility that hydrogen is exported to industrialised countries instead of the potential supplier countries pursuing their own decarbonisation policies and overcoming the energy poverty that usually prevails there.

The study was commissioned as an overview and literature study. No on-site research was in scope, but may be the included for a later study. The main objective of the present study is to provide more clarity on the extent and timeframes for countries of the Global South to be able to supply green hydrogen to industrialised countries and above all the conditions for these to be on fair terms. In this context, "fair" means that the needs of the population of the supplier countries must be the principal considerations of a sustainable export strategy on the part of these countries and an import strategy on the part of the buyer. Arepo GmbH is extending sustainability criteria already established elsewhere for deliveries from the global South to include (further) social dimensions.

According to the German government's hydrogen strategy, care should be taken to ensure that imports of green hydrogen or derived energy carriers to Germany are "additional" and do not come at the expense of the often inadequate renewable energy supply in developing countries. However, all the countries in the focus of the German government have, for example, green energy quotas far below the quotas listed above that are required so thathydrogen electrolysis leads to reduction of green house emissions. Moreover, with the exception of Morocco, the share of households with access to electricity is currently comparatively low. The corresponding figures for Niger are 1% (green electricity quota) and 13% (connection to public electricity supply), for Morocco 19.7% and 99%, and for West Africa as a whole 28.8% and 54%. (bp, 2020)

In addition to the extended socio-ecological import criteria and the proposals for their legal implementation, the study therefore develops the idea of "Additionality 2.0". This involves accompanying measures to ensure that the development of a hydrogen export infrastructure not only does not impede the supplier countries' own development, but also guarantees an additional benefit for them. Such accompanying measures could be additional investments in green energy plants and corresponding infrastructure on site, on a relevant scale in addition to those wind or photovoltaic plants that are needed for the electrolysis plants themselves. These would require a correspondingly extensive availability of land and water as well as the avoidance of conflicts of use with the local population and biodiversity.

The study of Arepo GmbH is a valuable contribution to the debate on social and ecological guidelines for the future import of hydrogen in the sense of a climate-friendly foreign trade policy. It is useful for the further development of German and European hydrogen strategies as well as for the civil society debate in the countries of the global South.

**Conclusions**

Experience with imports of agrofuels has shown that in practice it is extremely difficult to implement the guidelines required in a "watertight" and legally binding manner. Consequently, the Rosa Luxemburg Foundation concludes that early deliveries of hydrogen in particular are practically impossible, at least from West Africa. German and European policy-makers must be prepared to import only a very limited amount of socio-ecologically sustainable green hydrogen in the foreseeable future. This circumstance must have an impact on policies in Germany and Europe, especially since shortages of available green hydrogen could become the Achilles' heel of climate protection. In this respect, a waste of hydrogen in inefficient applications (automobiles, heating buildings) could be at the expense of those applications that have an unavoidable demand for hydrogen in the course of the industrial transformation (steel, chemicals, later also aviation and shipping, so-called "no-regret applications").

However limited the short-term import prospects may be, in the long term there is certainly nothing that fundamentally contradicts importing at least part of the PtX that will be needed in the future from countries in the global South that have particularly good climatic and other conditions. However, the eco-social guidelines described in the Arepo study, including the criterion of "additionality 2.0", would have to be respected. On the other side, such hydrogen exports can offer suitable supplier countries an opportunity to diversify their export structure, reduce problematic exports of fossil and other raw materials, and generate revenues within the framework of a renewable resource that they need in the fight against poverty and for other social and ecological tasks.

However, at this moment, a transformation of the energy and transport sectors in Germany and Europe as a whole that would largely rely on such fuels to heat homes and fuel road transport while avoiding to increase energy efficiency of buildings or to base urban mobility on public transport will be counter-productive. The supply of the vast quantities of electricity-based fuels that would be needed in that scenario will hardly be available. It would require the development  extended economic sectors abroad where not even any  beginnings exist today - some of which located in extremely sensitive regions outside Europe. Pushing for imports here by hook or by crook could pave the way for new neo-colonial structures.

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## Schlussfolgerungen der Rosa-Luxemburg-Stiftung

## auf Basis der Studie „Fair Green Hydrogen: Chance or Chimera in Morocco, Niger and Senegal?“ zum politischen Umgang mit Wasserstoffimporten aus dem globalen Süden

### Hintergrund

Wasserstoff ($H_2$) und seine Folgeprodukte werden künftig eine wichtige Rolle bei der Dekarbonisierung der Volkswirtschaften spielen, und zwar vor allem in vier Einsatzgebieten:

1. Wo der deutlich effizientere direkte oder batteriegestützte Stromeinsatz nicht, oder nur unter enormem Aufwand möglich wäre (etwa im Flug- und Seeverkehr, ggf. in Teilen des Schwerlastverkehrs) kann Wasserstoff über Brennstoffzellen bzw. über wasserstoffbasierte flüssige oder gasförmige Brennstoffe als so genannte synthetischen Kraftstoffe (Synfuels) zum Einsatz kommen.
2. Wasserstoff wird auch als Langzeit-Speichermedium dienen, vor allem um die Energieversorgung über Wasserstoff-Gasturbinen in jenen Zeiten des Winters abzusichern, in denen kein Wind weht und keine Sonne scheint („Dunkelflaute“).
3. Wasserstoff wird benötigt, um Treibhausgase zu vermeiden, die in der Industrie nicht energiebedingt entstehen, sondern aufgrund von stofflichen Prozessen, etwa in der Stahlproduktion. In der Industrie sind aber auch thermische Verwendungen von Wasserstoff und Folgeprodukten zur Ablösung von Erdgas bei Hochtemperaturprozessen möglich.
4. Aus Wasserstoff und Kohlenstoff erzeugte Kohlenwasserstoffverbindungen werden (neben biogenen Rohstoffen, die aber ein sehr begrenztes Potential haben) in der chemischen Industrie Erdgas und Erdöl als Grundstoff ersetzen.

Alle diese Anwendungen basieren – wenn sie nachhaltig erzeugt werden sollen – auf Wasserstoff, der mittels Ökostrom aus Elektrolyseuren gewonnen und gegebenenfalls mit Kohlenstoff verbunden wird. Letzterer muss klimaneutral gewonnen werden.

Dass Wasserstoff das „Öl der Zukunft“ wird, wie häufig behauptet, ist zweifelhaft. Zwar weisen der Stoff und seine Folgeprodukte eine hohe Energiedichte auf und sind darum vielseitig und ausdauernd nutzbar. Sie haben aber zugleich einen gravierenden Nachteil: Die Herstellung von grünem Wasserstoff über einen Elektrolyse-Prozess mittels Ökostrom ist enorm energie- und kostenintensiv – und dies wird absehbar auch so bleiben. Wird Wasserstoff nicht in reiner Form verwendet, sondern mit Kohlenstoff in flüssige oder gasförmige Stoffe eingebaut, so benötigen diese Prozesse noch zusätzlich große Mengen Energie. Ökostrom ist jedoch ein wertvolles Gut. Verfügbare Flächen und benötigte Rohstoffe sind knapp und häufig konfliktbeladen – sowohl hierzulande als auch im Ausland.

Aufgrund des Zahlengerüstes der Deutschen Wasserstoffstrategie lässt sich abschätzen, dass die Bundesregierung mittel- und langfristig 70 bis 80 Prozent des in Deutschland genutzten

Wasserstoffs importieren will. Auch verschiedenste Akteure der Wirtschaft und beinah die gesamte relevante Studienlandschaft gehen davon aus, dass der benötigte grüne Wasserstoff in all seinen chemischen Transformationsprodukten größtenteils aus dem Ausland kommen wird.

Für die Bundesregierung stehen auf längere Sicht als Lieferanten für den grünen Wasserstoff unter anderem die nord- und westafrikanische Staaten im Fokus. In den Wüsten des Maghreb könnten große Anlagen aus Sonnen- und Windstrom zu geringen Kosten Wasserstoff und synthetische Treibstoffe (kurz „PtX“) herstellen, argumentiert die Industrie. Nach einem Potenzialatlas (Forschungszentrum Jülich, 2021), den die vergangene schwarz-rote Bundesregierung bereits für Westafrika hat erstellen lassen, könnten in dieser Region bis zu 165.000 TWh Wasserstoff produziert werden (BMBF, 2020b).

Die mit Wasserstoff-Importen verbundenen Probleme werden bislang allerdings wenig kommuniziert. Laut einer Meta-Studie des Öko-Instituts kann die Herstellung strombasierter Stoffe zu höheren $CO_2$-Emissionen führen als die Nutzung fossiler Alternativen, solange noch fossile Erzeugungskapazitäten im Stromsystem sind (Heinemann et al., 2019). Eine Umstellung der Wasserstoff-Herstellung von Erdgas-Hydrierung auf Elektrolyse beispielsweise mache deshalb erst bei etwa 70 % Ökostrom im Netz wirklich Sinn. Ein Klimavorteil von strombasierten Substituten für Diesel und Erdgas ergebe sich gar erst ab einem rund 80-prozentigen Ökostromanteil an der Stromerzeugung. Für Deutschland sind solche Werte nach den Plänen der Bundesregierung frühestens um das Jahr 2030 zu erwarten (Stand 2021: 42,6 % Ökostrom am Bruttostromverbrauch).

Demnach stellt sich also bereits für Deutschland als Industrieland die Frage der Sinnhaftigkeit früher großskaliger Wasserstoff-Anwendungen jenseits von Pilotprojekten und einem klug gesteuerten Aufwuchspfad. So würde z.B. eine PtX-Produktion für den Verkehrssektor mit der gegenwärtigen Ökostromquote Deutschlands mehr Treibhausgase produzieren als der Einsatz der konventionellen Kraftstoffe. Erst recht würde eine Wasserstoffproduktion im globalen Süden für Europa – ohne weitere begleitende Maßnahmen – die Dekarbonisierung in den südlichen Ländern behindern. Dies gilt grundsätzlich auch, wenn die Investoren des Globalen Nordens nicht nur Elektrolyseanlagen, sondern auch die zu ihrem Betrieb benötigten Ökostromanlagen in den südlichen Ländern aufbauen und finanzieren würden. Schließlich würden mit hoher Wahrscheinlichkeit vor allem die von der Naturausstattung besonders geeigneten (Windhöfigkeit, Sonneneinstrahlung, Wasserverfügbarkeit, gute Wasserkraftstandorte, etc.) und somit preiswertesten Standorte dafür genutzt werden, die dann nicht mehr für die heimische Ökostromproduktion zur Verfügung stünden.

**Studienauftrag und zentrale Ergebnisse aus Sicht der Stiftung**

Wie realistisch Wasserstoffimporte aus dem Globalen Süden sind bzw. welche Rahmenbedingungen es dafür geben müsste, um diese sozial und ökologisch gerecht zu gestalten, untersucht die vorliegende Arbeit der Arepo GmbH im Auftrag der Rosa-Luxemburg-Stiftung (RLS) am Beispiel der drei Staaten Senegal, Niger und Marokko. Danach ist offensichtlich in absehbarer Zeit kaum mit Importen zumindest aus Senegal und Niger zu rechnen: Frühere Importe seien nicht ausgeschlossen, so die Studie, aber extrem voraussetzungsvoll. Um erneute neokoloniale Verhältnisse zwischen Erzeuger- und Importländern zu verhindern, müssten auch spätere Importe unter strikten Rahmenbedingungen stattfinden. Dazu gehöre, auszuschließen, dass Wasserstoffexporte in die Industrieländer zu Lasten der Bemühungen in den potentiellen Lieferländern gingen, ihre eigene Dekarbonisierungspolitik zu betreiben und die in der Regel vorherrschende Energiearmut zu überwinden.

Die Studie wurde als Überblicks- und Literaturstudie beauftragt, Vor-Ort-Recherchen waren für diese Arbeit nicht vorgesehen. Solche könnten aber Gegenstand einer späteren Untersuchung sein. Zunächst sollte die vorliegende Studie mehr Klarheit darüber schaffen, inwieweit, in welchen Zeiträumen und vor allem unter welchen Bedingungen Länder des Globalen Südens in der Lage sein könnten, an Industriestaaten grünen Wasserstoff zu fairen Bedingungen zu liefern. Fair bedeutet in diesem Zusammenhang, dass die Bedürfnisse der Bevölkerung der Lieferstaaten Ausgangs- und Endpunkt einer nachhaltigen Exportstrategie auf Seiten dieser Staaten sowie einer Importstrategie auf der Abnehmerseite sein müssen. Arepo GmbH erweitert dazu bereits anderweitig aufgestellte Nachhaltigkeitskriterien für Lieferungen aus dem globalen Süden um (weitere) soziale Dimensionen.

Laut Wasserstoffstrategie der Bundesregierung soll darauf geachtet werden, dass ein Import von grünem Wasserstoff oder darauf basierenden Energieträgern nach Deutschland „zusätzlich“ ist und nicht zu Lasten der häufig unzureichenden erneuerbaren Energieversorgung in den Entwicklungsländern geht. Doch alle der im Fokus der Bundesregierung stehenden Länder haben beispielsweise real Ökostromquoten, die weit unterhalb der oben angeführten Quoten liegen, ab denen die Wasserstoff-Elektrolyse zu THG-Einsparungen führt. Außerdem ist der Anteil der Haushalte mit Zugang zur Stromversorgung mit Ausnahme Marokkos gegenwärtig vergleichsweise niedrig. So betragen beispielsweise die entsprechenden Werte für Niger 1 % (Ökostromquote) bzw. 13 % (Anschluss an öffentliche Stromversorgung), für Marokko 19,7 % bzw. 99 % und für Westafrika insgesamt 28,8 % bzw. 54 %. (bp, 2020)

Neben den erweiterten sozialökologischen Importkriterien und den Vorschlägen zu ihrer rechtlichen Implementierung entwickelt die Studie daher die Idee einer „Zusätzlichkeit 2.0“. Dabei geht es um begleitende Maßnahmen, die gewährleisten sollen, dass der Aufbau einer Wasserstoff-Exportinfrastruktur nicht nur die eigene Entwicklung der Lieferländer nicht behindert, sondern einen Zusatznutzen für sie garantiert. Solche begleitenden Maßnahmen könnten etwa zusätzliche Investitionen in Ökostromanlagen und entsprechender Infrastruktur vor Ort sein, und zwar in einem relevanten Maßstab zusätzlich zu jenen Wind- oder Photovoltaik-Anlagen hinaus, die für die Elektrolyseanlagen selbst benötigt werden. Diese würden eine entsprechend ausgedehnte Flächen- und Wasserverfügbarkeit sowie das Vermeiden von Nutzungskonflikten mit der heimischen Bevölkerung und der Biodiversität voraussetzen.

Die Arbeit von Arepo GmbH ist ein wertvoller Beitrag dafür, die Debatte um soziale und ökologische Guidelines beim künftigen Import von Wasserstoff im Sinne einer klimagerechten Außenhandelspolitik zu bereichern. Das gilt sowohl für die Weiterentwicklung der deutschen und europäischen Wasserstoffstrategien, also auch für die zivilgesellschaftliche Debatte in den Ländern des globalen Südens.

**Schlussfolgerungen**

Die Erfahrung mit Importen von Agrokraftstoffen haben gezeigt, dass es außerordentlich schwierig ist, in der Praxis entsprechende Guidelines „wasserdicht" und rechtsverbindlich umzusetzen. Entsprechend geht die Rosa-Luxemburg-Stiftung davon aus, dass insbesondere frühe Lieferungen von Wasserstoff zumindest aus Westafrika praktisch ausgeschlossen sind. Die deutsche und europäische Politik muss sich folglich darauf einstellen, in ansehbarer Zeit nur in einem sehr begrenzten Ausmaß sozialökologisch nachhaltig erzeugten grünen Wasserstoff importieren zu können. Dieser Umstand muss Auswirkungen auf die Politik hierzulade haben, zumal Engpässe an verfügbarem grünen Wasserstoff zur Achillesferse des Klimaschutzes werden könnten. Insofern könnte eine Verschwendung von Wasserstoff in ineffizienten Anwendungen (Automobile, Gebäudewärme) zu Lasten jener Anwendungen gehen, die im Zuge des Umbaus einen unabwendbaren Wasserstoffbedarf haben (Stahl, Chemie, später auch Luft- und Seefahrt, so genannte „No-regret-Anwendungen").

So beschränkt die kurzfristigen Importaussichten sein mögen: Auf lange Sicht spricht sicherlich nichts grundsätzlich dagegen, zumindest einen Teil zukünftig benötigter PtX auch aus solchen Ländern des globalen Südens zu importieren, die besonders gute klimatische und sonstige Bedingungen dafür aufweisen. Dafür müssten jedoch die in der Arepo-Studie beschriebenen ökosozialen Guidelines einschließlich des Kriteriums „Zusätzlichkeit 2.0" eingehalten werden. Umgekehrt können solcherart Wasserstoffexporte für geeignete Lieferländer eine Chance bieten, ihre Exportstruktur zu diversifizieren, problematische Exporte von fossilen und anderen Rohstoffen zurückzufahren und Einnahmen im Rahmen einer nunmehr erneuerbaren Ressource zu generieren, die sie im Kampf gegen Armut und für andere soziale und ökologische Aufgaben benötigen.

Eine Energie- und Verkehrswende hier und heute aber, die auf solche Brennstoffe für einen Großteil der Häuser und den Straßenverkehr setzen würde, um einem Mehr an Gebäudeeffizienz oder einer tatsächlichen Mobilitätswende aus dem Weg zu gehen, dürfte dennoch auf tönernen Füßen stehen. Denn die Bezugsoption für die Unmengen von strombasierten Kraftstoffen, die dann benötigt würden, wäre mehr als wacklig. Sie setzte auf riesige Wirtschaftszweige im Ausland, die heute noch nicht einmal im Ansatz existieren – und teilweise in äußerst sensiblen Regionen außerhalb Europas lägen. Hier nun Importe auf Biegen und Brechen zu forcieren, könnte neuen neokolonialen Strukturen den Weg ebnen.

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# Summary

In a world where the dooming climate crisis increasingly turns into a planetary crisis, the development of a sustainable and clean 'hydrogen economy' is considered essential if the world wants to keep the hope alive to limit global warming to 1.5°C above pre-industrial levels. Many countries strive for 'carbon-neutral' societies and economies - Germany, for example, has set this aim for 2045. Alongside (1) the phase-out of fossil fuels, (2) the development of renewable energy generation and (3) increased energy efficiency, the establishment of (4) a hydrogen infrastructure as an avenue to utilize green electricity in sectors and industries where fossils has been used in material processes up to now (e.g. reduction in steel production), where direct electrification is hardly possible (e.g. air and sea transport), and as a carbon-free energy source in high-temperature processes and for future reconversion to electricity during dark doldrums and as a storage medium is planned.

As of now, discussions surrounding hydrogen are mostly concerned with the technical aspects of scaling up global green hydrogen production quickly, vastly ignoring the potential social and ecological challenges coming with this (not so) new energy carrier. Yet, the establishment of a new global infrastructure and a completely new branch of the global energy sector in the form of a hydrogen rush, provides not only a global economic opportunity, but a significant risk of either sidelining developing countries, or repeating the negative economic, social and environmental experiences that were linked to extractive industries and the exploitation of fossil energy resources in the past. The risk of 'green colonialism' (Scita et al., 2020) must be reflected and taken into account.

Green hydrogen can in principle be produced in many countries and regions of the world. Decision makers see an opportunity to include the sun- and wind-rich regions and countries in the Global South in producing hydrogen to meet the enormous global demand that is starting to develop. Specifically, Germany's former research minister Anja Karliczek, emphasized that West Africa alone has the potential to produce green hydrogen equivalent to 1.500 times Germany's demand in 2030 (*Bundesministerium für Bildung und Forschung* [BMBF], 2021b). Against this background, this study looks specifically at the German demand for green hydrogen and asks whether it can be met by imports, especially from the Global South, and under which conditions this could be done in a both socially and ecologically acceptable way for the countries exporting hydrogen.

# 1 Hydrogen – the technical dimension

The first element of the periodic table, hydrogen is a highly reactive colorless gas. In contact with oxygen, it is unstable which is the reason why there are no harvestable natural resources. In technical systems, hydrogen is both an energy carrier and a resource. Hydrogen can be produced from electricity and water, and its climate impact depends on the source for this power. In order to classify the various processes and energy sources for the production of hydrogen, a spectrum of nine different hydrogen 'colors' has been established in the political discourse.

### Different "colors" of hydrogen

As of now, **"grey hydrogen"** is by far the most widespread form of hydrogen production. It is produced by steam reforming from fossil sources like methane or coal. The carbon dioxide emitted in this process is released into the atmosphere. This leads to a considerable carbon dioxide footprint. In the production of **"blue hydrogen"** captures parts of the carbon dioxide and stores it, ensuring that the carbon dioxide cannot be released into the atmosphere. Yet, blue hydrogen will still be associated with some carbon emission, from the production and possible leakage of methane or coal, and the generation of the electricity used for the steam reforming process. Carbon emissions can therefore be reduced in blue hydrogen production, but not eliminated (IRENA, 2020a). In addition, underground storage is controversial.

There are several other "colors" of hydrogen, associated with different sources for the energy that is used to produce it, including pink for nuclear power. **"Turquoise hydrogen"** is still in the pilot phase but shall be produced via pyrolysis, which extracts hydrogen from fossil methane, leaving behind a solid block of carbon.

For all colors, emissions can be generated by the production of methane or coal, and the energy used in the process. Only **"green hydrogen"** is produced with renewable electricity through a different process, the electrolysis of water into hydrogen and oxygen. This form of hydrogen production is therefore best suited for a fully sustainable energy transition.

### Input factors for hydrogen production

As a nascent industry, all aspects of the hydrogen value chain (production facilities, input factors, transportation facilities) are currently expensive and their supply is insufficient.

The production process for green hydrogen is the electrolysis of water, requiring an appliance in which this happens (the "electrolyser"), water as well as electricity. While the process itself is not new, at this point, industrial-scale electrolysers are still expensive. With the expansion of the industry, their cost will drop.

About 0,27 liter of water are needed to produce one kilowatt hour (kWh) hydrogen alone (IEA, 2019). In general, in non-arid regions and countries such as Germany the freshwater input needed for local hydrogen production is unlikely to be noticed (Umweltbundesamt 2020). In arid-world regions such as in large parts of Africa, however, there is a much higher risk that such water demand will exacerbate existing water conflicts or generate new ones, given the scarcity of water. Desalinated seawater is considered as an alternative but requires additional electricity and infrastructure.

The production of hydrogen is very energy-intensive. Without any control for the quality of the electricity, hydrogen production can cause additional carbon dioxide emissions. Öko-Institut (2019) claims that in order to ensure that hydrogen is in fact greener than conventional fuels, the share of green power on the grid is higher than 70 %. Currently, renewable electricity in most situations and countries is typically not yet covering the demand, and therefore it can be expected that hydrogen production will require additional renewable electricity capacity.

Hydrogen from Africa for the German market needs to be transported, through pipelines or by ships, which means additional infrastructural and energy requirements. So far, only one prototype for a liquid hydrogen transport ship exists (Lloyd's Register, 2022), and port facilities are rare. Alternatively, hydrogen could be transported in the form of other chemicals, e.g., ammonia or as so-called "e-fuels" i.e., Kerosene or Diesel that is produced from hydrogen and a carbon source.

# 2 Green Hydrogen Demand

While it is clear that overall demand will go up, there is significant uncertainty about the true future size of the global, European or German market. Initially, roughly until the year 2030, the forecasts for required green hydrogen uniformly predict a rather low demand overall as hydrogen will continue to be very expensive to generate, compared to natural gas.

In 2030, across all scenarios a maximum need of 80 TWh of green hydrogen is predicted for Germany (Ariadne, 2021b). For 2045, a total demand of 423 TWh of green hydrogen and PtL in Germany has been calculated by Prognos et al. (2021). Almost 80 % will be imported. The scenario assumes that, at that point in time, most hydrogen will be used in power generation. In industry, hydrogen will be mainly used for the direct reduction of iron ore for $CO_2$-free steel production, as a raw material in the chemical industry and for the generation of process steam. E-fuels will be used in the national and international shipping and aviation sectors (Prognos et al., 2021).

At the global level, IEA assumes that there is demand for 19,444 TWh of "low-carbon" hydrogen by 2050 (IEA, 2021b). Germany would constitute little more than 2 % of this demand (its share in global GDP at the time of writing is about 3,3 %).

# 3 Current and Future Supply of Green Hydrogen

Today, most hydrogen is produced (and consumed) in the US, China and the Middle East. But many countries potentially have access to the input factors necessary for green hydrogen production (electrolysers, water, green electricity, and transport infrastructure), and thus a potential supplier role. IRENA finds that "green hydrogen could disrupt global trade and bilateral energy relations, reshaping the positioning of states with new hydrogen exporters and users emerging" (IRENA, 2022b). In addition to the potential of renewable energies and the existing infrastructural and industrial base, transport costs in particular play an important role in the production and import/export of hydrogen.

Africa has a comparatively high technical potential to produce green hydrogen (FZ Jülich, 2022). IRENA (2022a) juxtaposes the production potential of all world regions for hydrogen under 1.5 USD/kg by 2050, and finds that Sub-Saharan Africa could produce over 75.000 TWh of hydrogen, the Middle East and North Africa 56.000 TWh, North America 36.500 TWh, Oceania 35.000 TWh, South America 31.000 TWh, the rest of Asia 27.000 TWh and Europe 2.400 TWh. Combined with the geographic proximity, Africa is a likely source for hydrogen for Europe's and Germany's approach

Germany's approach to hydrogen is shaped by the German government's National Hydrogen Strategy of 2020. In the export-import context, Germany's Act on Corporate Due Diligence in Supply Chains and the hydrogen criteria of the National Hydrogen Council are also of particular relevance.

# 4 Hydrogen politics of Germany and the EU

### Germany

The new German government coalition of Social Democrats, Greens and Liberals (since 2021) has recently doubled the aim of the former government coalition under Angela Merkel of installed hydrogen electrolyser capacity from 5 GW to 10 GW by 2030 (Radowitz, 2021). This update will be embedded in an overhaul of the existing National Hydrogen Strategy (*Nationale Wasserstoffstrategie* – NWS), passed in 2020. It is noteworthy that this strategy already includes qualitative requirements and criteria for hydrogen imports. Specifically, it states the principle that every import of green hydrogen or its derivatives must take place on top of domestic energy production ('additionality principle'). This criterion is fundamental to addressing some of the most important economic and ecological challenges associated with hydrogen production.

The main instrument for Germany's foreign trade policy regarding hydrogen are bilateral partnerships in the energy sector (NWS measure 34 and 36). Bilateral Energy Partnerships are intended to "bring together high-level intergovernmental dialogue with practical, goal-oriented project work" (GIZ, 2021a), across energy-related areas and on country-specific priorities. Germany maintains a number of such energy partnerships, including eight partnerships that are specifically focused on hydrogen (Dietz-Polte & Vacha, 2021; GIZ, 2021a). These partnerships exist with countries in both the Global North and the Global South. Three of them build on existing Bilateral Energy Partnerships (Chile, Morocco, South Africa). In addition to these, hydrogen partnerships are formed with Australia, Canada, Japan, Namibia and Saudi-Arabia.

Generally, the new German Act on Corporate Due Diligence in Supply Chains (‘*Lieferkettensorgfaltspflichtengesetz*’ [LkSG]) is intended to improve the international human rights situation by defining responsibilities for the management of supply chains. German companies have to ensure that they fulfil a number of due diligence obligations against human rights violations (BMWK, 2022). These can include environmental and social aspects. But the law needs to be further tested in practice and litigation. In addition to hydrogen production and water resources, it could also relate to metals needed for electrolysers (Johann, 2022).

### EU Level

Similar to, and to some extent aligned with Germany, the European Commission also works on ‘hydrogen diplomacy’, with energy partnerships. In addition, the EU’s ‘Hydrogen strategy for a climate-neutral Europe' follows a similar logic to Germany’s phased approach as outlined by Matthes et al. (2021), first building the foundation by the mid-2020s domestically, and then scaling up rapidly in the following two to three decades.

Criteria for green hydrogen at the EU level are also being established (Oyarzabal et al., 2022). As of late February 2022, the EU Commission is preparing to launch an EU-wide database to certify the carbon footprint of hydrogen – of which 96 % are currently reliant on fossil fuels – and other so-called ‘low-carbon’ fuels in a harmonized way (Kurmayer, 2021). By 2050, the EU expects almost ¼ of global energy demand to be met by green hydrogen, thus playing a key role in its own climate goals (EC, 2020). One important step towards the implementation of the EU Hydrogen Strategy was the legislative package on hydrogen and decarbonized markets in December 2021, which is currently (as of March 2022) still under review. The legislative package also proposes new rules for the development of a hydrogen market in the EU. These bring legal clarity to the definition and role of green and low-carbon hydrogen within the EU.

It is anticipated that a supply chain law will also be passed at the European level. Non-governmental organizations (NGOs) and other political actors will most likely be plaintiffs for supply chain due diligence at the EU level as well, since each EU country must transpose the EU directives into national law.

### Foreseeable consequences of an unrestrained hydrogen economy

If done right, the supply gap for hydrogen offers a significant development opportunity for countries in the Global South and specifically in Africa, satisfying local needs, providing jobs and continuous income from a participation in energy markets as a supplier. But large investment projects in the Global South, specifically with an export-orientation to provide basic commodities for the Global North, reminisce of exploitative economic relationships and practices of the colonial times and the oil era. Such developments need to be avoided.

Upscaling hydrogen production can perpetuate existing or create new practices of ‘economic colonialism’, even under the guise of being ‘green’, continuing in a pattern in which the survival and security of those living within Western borders are put above the needs of those living outside of it. Specifically, there is a risk that hydrogen production capacities come at the expense of national efforts to achieve national development objectives, including climate neutrality, or the provision of basic services like electricity or water supplies.

Among others, van de Graaf stresses that the ‘Hydrogen Hype’ is the product of the expectation that hydrogen could “become the next great prize, a zero-carbon version of oil” (Van de Graaf, 2021; p. 30). On the other hand, establishing infrastructure for hydrogen transport seems simpler and less costly along established trade routes – in other words, the winners of globalization are also in the pole position to become the winners of the ‘Hydrogen Economy’, irrespective of their location factors (water, renewable power, investment capital). In that sense, in line with the definition of Adoko et al. (2021, p. 196), neo-colonial structures in hydrogen can also arise in the neglect to include Africa into the economic and development opportunities that arise from the new technology. Therefore, it can be seen as relevant that countries of the Global South build up hydrogen production capacities both for their own needs and for export, and thus overcome their current dependence on fossil fuels and corresponding structures. Export of hydrogen to countries of the Global North should be tied to criteria that ensure alignment with the Sustainable Development Goals, and the maximization of local benefits from the deployment of these new technologies.

# 5 Case studies

In order to show both the possibility and potential of producing and exporting ‘fair green hydrogen’ as well as the multitude of challenges in quickly upscaling the production of green hydrogen on African continent, three case studies have been chosen: Morocco, Niger and Senegal. Niger is a good example of a landlocked country, which with its arid natural conditions is typical for some African states. Landlocked countries (like Niger) face different challenges than coastal states in terms of logistics and transport routes. As an arid country, water availability is an additional challenge. The questions of space and land use plays a rather subordinate role, as the population and settlement density are naturally lower or limited to only small parts of the country. Senegal, as a coastal state with less availability of land, but a currently ongoing fossil fuels boom, is also prototypical for a significant number of African states. Morocco as a large country with a considerable headstart in solar technology is considered in a pole position for the hydrogen economy – in mid-February 2022 the EU unveiled plans to invest EUR 1.6 bn in Morocco as part of the EU’s EUR 300 bn

‘Global Gateway’ infrastructure plan, Europe’s first-ever African scheme and response to China's Belt and Road Initiative (DW, 2022).

All three case studies demonstrate how ecological factors and social concerns will continue to prove a major barrier to scaling up green hydrogen infrastructure, as long as the government takes them into account. Infrastructure issues are also a hurdle. Specifically, the need for desalination plants and the safe disposal of their waste is challenging. But ensuring that the local population benefits directly from both (new) desalination plants as well as economically deserves additional interventions.

Green hydrogen production in Niger is more difficult compared to other locations in Africa, but not impossible. Niger currently gives no reason to believe that at some point in the near- to medium-term future, green hydrogen could be produced in a ‘fair’ way or easily be transported either southwards to Nigeria or northwards to Algeria and then further to Europe. If the country decides – and there could be good reasons for it – to invest in hydrogen production plants, questions of infrastructural connection and water availability must first be clarified.

In Senegal, too, the current focus is on reaping the “benefits” from gas and oil rather than hydrogen. It should be prevented that (green) hydrogen follows the economic model of ‘enclave production’, i.e., of extraction and export. Large population groups have hardly benefited from the vast natural resources of the coastal country. For green hydrogen to not perpetuate the same pattern, the imposition of socially and ecologically fair criteria will be inevitable.

# 6 Criteria for Fair and Green Hydrogen

The discussion so far makes clear that hydrogen production must not take place at the expense of the country's development, it must not exclude the Global South, and if the Global South is integrated into hydrogen production, this has to be done on an equal footing. The development of hydrogen production in Global South countries must support their independence and own capacities. This means that there is another dimension to hydrogen besides the "green" dimension, which relates to fairness and social sustainability. Relationships and partnerships should be based politically on (1) the ability of a country to steer investment flows and development dialogues on all levels (international, national, local) to overcome historical or conventional power relations, (2) competence and capability transfer, (3) the creation of economic opportunities in the exporting country (4) fair prices (for the hydrogen sold) as well as for the production components and (5) independence or diversification options for exporting countries (no exclusive rights for importing countries). Furthermore, from an economic perspective, cooperation should be designed in such a way that exploitative structures are prevented, and the interests of foreign economic actors are not at the expense of the local population and its needs. A large part of the value chain of hydrogen production capacities, as early as in the construction phase, should take place locally and in cooperation with local and regional economic actors.

In order to ensure the implementation of these guiding principles, the principle of additionality described above is to be expanded into what could be called 'Additionality 2.0'.

'Additionality 2.0' describes accompanying measures to ensure that the development of hydrogen export infrastructure not only does not hinder the development of exporting countries, but also guarantees added value for supplier countries. Such accompanying measures could be, for example, additional investments in renewable energy plants and corresponding infrastructure on site, on a relevant scale in addition to those wind or photovoltaic plants that are needed for the electrolysis itself. These would require a correspondingly extended availability of land and water as well as the avoidance of conflicts of use with the local population and biodiversity. Thus, the principle of 'Additionality 2.0' goes beyond a pure "do no harm" approach, and calls for '+X solutions' for hydrogen projects.

On this basis, the study proposes fourteen criteria based on four overarching dimensions: Social, Ecological, Economic and Political, to ensure that the right questions can be asked when planning or discussing hydrogen projects in Africa.

# 7 Requirements for the implementation

The immediate implementation of the entire catalogue of criteria is of course unachievable. A successive implementation and the connection to already existing political processes and regulations requires certain developments in the areas of infrastructure, energy capacity, financing and institutions.

### Infrastructure

Participation in the global hydrogen economy can also open up new development potential to countries that are currently less developed. The infrastructural 'bridge-building' to Africa must be started and largely financed from Europe. In addition to the cost aspect, geopolitical and developmental considerations must also be taken into account when planning the infrastructure. This also explicitly applies to the transnational planning of the individual components of the hydrogen production chain (electrolysers, electricity, water).

Since the development of the corresponding infrastructure is complex, cost-intensive and takes a long time (both in Africa and on the importing side in Germany and Europe) and corresponding path dependencies will arise here, it is advisable that the infrastructure is not designed for 'dual-use', i.e. that the supplier countries do not focus on fossil exports and hydrogen at the same time, but that the infrastructure development in question is clearly focused on hydrogen. Unlike in the European or Eastern European context, in the African context there is little recourse to already existing infrastructure (which, in case of doubt, still needs to be adapted to hydrogen). This opens up the opportunity to find new useful and optimal solutions for logistics in cooperation with the African partner countries without already existing restrictions. From the German side, this process should be approached via the EU or in close coordination with the EU.

#### Energy capacity building

In principle, there is great renewable energy potential in all West African countries. But the energy for hydrogen production needs to be made available on top of the domestic needs. In the case studies on Senegal and Niger, it became clear that these countries still have very low RE quotas in their electricity mix. Producing hydrogen from grid electricity would not only reduce the availability of this power for other purposes, but also not result in "green" hydrogen. Ambitious political strategies for the expansion of renewable energies and the electricity grid are needed here and they should be tied to legally binding contracts with the developers and funders of such infrastructure.

The additional renewable energies can be developed in parallel to the expansion of the energy system, with direct connection to the existing national or regional electricity grid or off-grid. In both cases, it is important that the partner countries or project actors involved (business enterprises, etc.) as well as civil society actors jointly find country-specific solutions and then implement them adapted to the respective circumstances. Hydrogen production requires a continuous and trouble-free availability of energy is important for hydrogen production, which is why corresponding battery or storage systems must be planned when using wind and solar power. Integrating this into the existing power grid could provide benefits for the local grid operations.

In addition, local upskilling and know-how and capacity building in the relevant fields should be an integral part of every hydrogen partnership. The establishment of hydrogen production and the associated expansion of renewable energies can be a door opener for this and open up corresponding sustainable business fields and development opportunities.

#### Financing

Germany avails of a number of options for funding such projects. Among them are a dedicated support program (*Förderrichtlinie)* for the National Hydrogen Strategy and the Economic Recovery Plan (BMWK, 2021b), German Export Credit Guarantees, KfW loans to government or through its Deutsche Investitions- und Entwicklungsgesellschaft (DEG) as project finance to the private sector.

In addition, indirect financing of hydrogen production projects is possible through the innovative funding instrument H2Global. For this instrument, 900 million euros were approved by the Federal Ministry for Economic Affairs and Climate Protection at the end of 2021. The approach of this instrument is that, in line with the sustainability criteria, green hydrogen or its derivatives are purchased via an intermediary at the corresponding currently high price and then sold at a lower market price (in competition with other types of hydrogen) and the price difference between green and grey hydrogen is covered by subsidies from the federal government (H2international, 2021).

It would be worth considering applying this approach to individual countries or groups of countries (e.g., western Africa) in order to stimulate the development of hydrogen production in a focused manner.

**Institution building**

Most importantly, the set of criteria to be found for fair green hydrogen must be legally anchored and implemented both in Germany and Europe and in the partner country. The discussions and findings must be fed into the corresponding political processes in order to create planning and action security for all actors involved. On the German side, initial approaches in this regard can be found, for example, in the funding guideline for international hydrogen projects or in the Act on Corporate Due Diligence in Supply Chains, but decisive criteria are not sufficiently formulated and will need to be fleshed out through litigation. Here support to NGOs can help solidify the interpretation of the legal requirements.

Additional prerequisites relate to the areas of research and training of skilled workers, including through broad-based exchange programs in the relevant disciplines, raising awareness among potential partners for the potential of hydrogen partnerships and to introduce the possibilities and advantages of the production of green and fair hydrogen in the political and public discourse. An involvement and the education of local NGOs can also be helpful here. NGOs could, for example, demand more ambitious decarbonization plans from their governments or make the option of producing fair green hydrogen for their transformation to climate neutrality more prominent in the respective national discourse.

It should be noted that it can be assumed that the enormous demand for green hydrogen, the long lead and build-up times and the highly dynamic technical developments will lead to an increase in the need for action in the future, but also in the scope for action, which will then have to be filled politically. There is a danger that in such dynamic developments the time for developing standards will be lost and much will be subordinated to the achievement of goals. Therefore, it makes sense to formulate criteria for the production of green and fair hydrogen as early as possible, so that processes and structures can already be aligned accordingly in the initial phase that is now beginning. The resulting path dependencies require consideration early-on.

## Zusammenfassung

In einer Welt, in der sich die drohende Klimakrise immer mehr zu einer planetarischen Krise ausweitet, wird die Entwicklung einer nachhaltigen und sauberen "Wasserstoffwirtschaft" als unerlässlich angesehen, um die Hoffnung aufrechtzuerhalten, dass die globale Erwärmung auf 1,5°C über dem vorindustriellen Niveau begrenzt werden kann. Viele Länder streben eine "kohlenstoffneutrale" Gesellschaft und Wirtschaft an – Deutschland zum Beispiel hat sich dieses Ziel für 2045 gesetzt. Neben (1) dem Ausstieg aus fossilen Brennstoffen, (2) dem Ausbau der erneuerbaren Energien und (3) der Steigerung der Energieeffizienz ist (4) der Aufbau einer Wasserstoffinfrastruktur zur Nutzung von Ökostrom in Sektoren und Industrien, in denen bei stofflichen Prozessen bislang Kohlestoff zum Einsatz kommt (z. B. Reduktion bei Stahlproduktion), bei denen die direkte Elektrifizierung kaum möglich ist (z. B. Luft- und Seeverkehr), sowie als kohlenstofffreier Energieträger bei Hochtemperaturprozessen und zur künftigen Rückverstromung bei Dunkelflauten und als Speichermedium geplant. Bislang dreht sich die Debatte um Wasserstoff hauptsächlich um die technischen Aspekte einer raschen Ausweitung der weltweiten Produktion von grünem Wasserstoff. Dabei werden jedoch die potenziellen sozialen und ökologischen Herausforderungen, die mit diesem (nicht ganz so) neuen Energieträger verbunden sind, weitgehend außer Acht gelassen. Der Aufbau einer neuen globalen Infrastruktur und völlig neuer Zweige globale Energie- und Rohstoffsektoren rund um Wasserstoff bietet jedoch nicht nur enorme wirtschaftliche Chancen, sondern birgt auch ein erhebliches Risiko. So besteht für die Länder des Globalen Südens zum einen die Gefahr von den Entwicklungen rund um Wasserstoff ausgeschlossen zu werden und zum anderen – als potenzielle Produktionsländer für Wasserstoff – das Risiko, dass sich die negativen wirtschaftlichen, sozialen und ökologischen Erfahrungen und Folgen wiederholen, die in der Vergangenheit mit der Ausbeutung und dem Export fossiler Energieressourcen verbunden waren. Das Risiko eines "grünen Kolonialismus“ (Scita et al., 2020) muss reflektiert und ernst genommen werden.

Grüner Wasserstoff kann prinzipiell in vielen Ländern und Regionen der Welt produziert werden. Aber insbesondere die sonnen- und windreichen Regionen und Länder des Globalen Südens sind prädestiniert, um den sich abzeichnenden enormen globalen Bedarf an grünem Wasserstoff zu decken. Die ehemalige deutsche Forschungsministerin Anja Karliczek betonte, dass allein Westafrika das Potenzial hat, grünen Wasserstoff zu produzieren, der dem 1.500-fachen des deutschen Bedarfs im Jahr 2030 entspricht (Bundesministerium für Bildung und Forschung [BMBF], 2021b). Vor diesem Hintergrund wird in dieser Studie speziell der deutsche Bedarf an grünem Wasserstoff untersucht und die Frage gestellt, ob er durch Importe, insbesondere aus dem Globalen Süden und Westafrika, gedeckt werden kann und unter welchen Bedingungen dies in einer sozial und ökologisch verträglichen Art und Weise für die exportierenden Länder geschehen könnte.

# 1 Wasserstoff - die technische Dimension

Wasserstoff, das erste Element des Periodensystems, ist ein hochreaktives, farbloses Gas. In Kontakt mit Sauerstoff ist Wasserstoff instabil, weshalb es nicht einfach aus der Umwelt entnommen werden kann. In technischen Systemen ist Wasserstoff sowohl ein Energieträger als auch Ressource. Wasserstoff kann aus Elektrizität und Wasser hergestellt werden, seine Klimabilanz hängt von der für den Herstellungsprozess genutzten Energiequelle ab. Um die verschiedenen Verfahren und Energiequellen zur Herstellung von Wasserstoff zu klassifizieren, hat sich im politischen Diskurs ein Spektrum von neun verschiedenen Wasserstoff-"Farben" etabliert.

### Verschiedene "Farben" des Wasserstoffs

Bislang ist **"grauer Wasserstoff"** die am weitesten verbreitete Form der Wasserstofferzeugung. Er wird durch Dampfreformierung aus fossilen Quellen wie Methan oder Kohle hergestellt. Das bei diesem Verfahren freigesetzte Kohlenstoffdioxid ($CO_2$) wird in die Atmosphäre abgegeben. Dies führt zu erheblichen $CO_2$-Emissionen. Bei der Herstellung von **"blauem Wasserstoff"** wird ein Teil des $CO_2$ aufgefangen und gespeichert, so dass das $CO_2$ nicht in die Atmosphäre gelangen kann. Dennoch ist blauer Wasserstoff immer noch mit einem gewissen $CO_2$-Ausstoß verbunden, und zwar durch die Produktion und einem möglichen Entweichen von Methan oder Kohle sowie durch die Erzeugung des für den Dampfreformierungsprozess benötigten Stroms. Die Kohlenstoffemissionen können daher bei der Produktion von blauem Wasserstoff verringert, aber nicht eliminiert werden (IRENA, 2020a). Darüber hinaus ist die unterirdische Speicherung umstritten.

Es gibt noch mehrere andere "Farben" des Wasserstoffs, die mit verschiedenen Energiequellen verbunden sind, die zu seiner Herstellung verwendet werden, darunter rosa für die Kernkraft. Der **"türkisfarbene Wasserstoff"** befindet sich noch in der Pilotphase und soll durch Pyrolyse hergestellt werden. Dabei wird der Wasserstoff aus fossilem Methan gewonnen wird, wobei ein fester Kohlenstoffblock zurückbleibt. Bei allen Farben können die Emissionen durch die Produktion von Methan oder Kohle und die dabei verwendete Energie entstehen.

Nur **"grüner Wasserstoff"** wird mit erneuerbarem Strom und durch ein grundsätzlich anderes Verfahren hergestellt, und zwar durch die Elektrolyse von Wasser in Wasserstoff und Sauerstoff. Diese Form der Wasserstofferzeugung ist daher am besten für eine vollständig nachhaltige Energiewende geeignet.

### Inputfaktoren für die Wasserstoffproduktion

Da es sich noch um einen jungen Industriezweig handelt, sind alle Aspekte der Wasserstoff-Wertschöpfungskette (Produktionsanlagen, Inputfaktoren, Transportmittel) derzeit teuer und die zur Verfügung stehenden Mengen sind noch unzureichend.

Für die Herstellung von grünem Wasserstoff durch die Elektrolyse wird ein Elektrolyseur, Wasser und Strom benötigt. Das Verfahren selbst ist zwar nicht neu, doch sind Elektrolyseure im industriellen Maßstab derzeit noch teuer. Mit dem Ausbau der Industrie werden ihre Kosten und damit die Produktionskosten von grünem Wasserstoff sinken.

Etwa 0,27 Liter Wasser werden benötigt, um eine Kilowattstunde (kWh) Wasserstoff zu erzeugen (IEA, 2019). In humiden Regionen und Ländern wie Deutschland ist der für die lokale Wasserstoffproduktion benötigte Süßwassereinsatz im Allgemeinen kaum zu bemerken (Umweltbundesamt 2020). In ariden Gebieten, wie in weiten Teilen Afrikas, ist das Risiko, dass der Bedarf einer Wasserstoffproduktion angesichts der Knappheit bestehende Wasserkonflikte verschärft oder neue schafft, deutlich höher. Die Entsalzung von Meerwasser ist eine Alternative, erfordert aber zusätzlichen Strom und Infrastruktur.

Die Produktion von Wasserstoff ist sehr energieaufwändig. Ohne jegliche Kontrolle des genutzten Stroms kann seine Produktion zusätzliche Kohlenstoffdioxidemissionen verursachen. Deswegen weist das Öko-Institut (2019) darauf hin, dass der Anteil des für die Wasserstoffproduktion genutzten Ökostroms im Netz mehr als 70 % betragen muss, um sicherzustellen, dass Wasserstoff tatsächlich grüner ist als herkömmliche Kraftstoffe. Gegenwärtig deckt der Strom aus erneuerbaren Energiequellen in den meisten Ländern des Globalen Südens in der Regel noch nicht einmal den eigenen Bedarf, so dass für die Wasserstofferzeugung zusätzliche Kapazitäten an erneuerbarer Strom erforderlich sein werden.

Wasserstoff aus Afrika für den deutschen Markt muss über Pipelines oder mit Schiffen transportiert werden, was zusätzlichen Infrastruktur- und Energiebedarf bedeutet. Bislang gibt es nur einen Prototyp für ein Flüssigwasserstoff-Transportschiff (Lloyd’s Register, 2022) und entsprechende Hafenanlagen sind rar. Alternativ könnte Wasserstoff in Form anderer Chemikalien transportiert werden, z. B. Ammoniak oder sogenannte "E-Fuels" (d. h. Kersoin oder Diesel) die aus Wasserstoff und einer Kohlenstoffquelle hergestellt werden.

## 2 Die Nachfrage nach grünem Wasserstoff

Es ist zwar klar, dass die Gesamtnachfrage nach grünem Wasserstoff steigen wird, doch bestehen erhebliche Unsicherheiten über die tatsächliche Größe des zukünftigen globalen, europäischen oder deutschen Marktes. Zunächst, etwa bis zum Jahr 2030, wird eine eher geringe Gesamtnachfrage nach grünem Wasserstoff prognostiziert, da Wasserstoff im Vergleich zu Erdgas in der Erzeugung weiterhin sehr teuer sein wird.

Im Jahr 2030 wird für Deutschland über alle Szenarien hinweg ein maximaler Bedarf von 80 TWh an grünem Wasserstoff vorhergesagt (Ariadne, 2021b). Für das Jahr 2045 wird durch Prognos et al. (2021) ein Gesamtbedarf von 423 TWh an grünem Wasserstoff und Power-to-Liquid (PtL) in Deutschland errechnet. Fast 80 % davon wird man importieren müssen. Das Szenario geht davon aus, dass zu diesem Zeitpunkt der meiste Wasserstoff in der

Stromerzeugung eingesetzt wird. In der Industrie wird Wasserstoff vor allem für die Direktreduktion von Eisenerz zur $CO_2$-freien Stahlerzeugung, als Rohstoff in der chemischen Industrie und zur Erzeugung von Prozessdampf eingesetzt werden. Wasserstoffbasierte E-Fuels werden in der nationalen und internationalen Schifffahrt und Luftfahrt genutzt werden (Prognos et al., 2021).

Auf globaler Ebene geht die IEA davon aus, dass bis 2050 ein Bedarf an 19.444 TWh "kohlenstoffarmen" Wasserstoff besteht (IEA, 2021b). Auf Deutschland würden etwas mehr als 2 % dieser Nachfrage entfallen (sein Anteil am globalen BIP beträgt zum Zeitpunkt der Erstellung dieses Berichts etwa 3,3 %).

# 3 Derzeitige und künftige Versorgung mit grünem Wasserstoff

Heute wird der meiste Wasserstoff in den USA, China und im Nahen Osten produziert (und verbraucht). Doch viele Länder haben zumindest potenziell Zugang zu den für die Produktion von grünem Wasserstoff erforderlichen Inputfaktoren (Ökostrom, Elektrolyseure, Wasser und Transportinfrastruktur) und könnten damit eine Exportrolle einnehmen. Grüner Wasserstoff könnte aufgrund neuer Export- und Importstrukturen eine Disruption und Neuordnung des Welthandels und die bilateralen Energiebeziehungen auslösen (IRENA, 2022b). Neben dem Potenzial der erneuerbaren Energien und der bestehenden infrastrukturellen und industriellen Basis spielen vor allem die Transportkosten eine wichtige Rolle bei der Produktion und dem Import/Export von Wasserstoff.

Afrika hat ein vergleichsweise hohes technisches Potenzial zur Erzeugung von grünem Wasserstoff (FZ Jülich, 2022). IRENA (2022a) vergleicht das Produktionspotenzial aller Weltregionen für Wasserstoff unter 1,5 USD/kg bis 2050 und stellt fest, dass Subsahara-Afrika über 75.000 TWh Wasserstoff produzieren könnte (der Nahe Osten und Nordafrika 56.000 TWh, Nordamerika 36.500 TWh, Ozeanien 35.000 TWh, Südamerika 31.000 TWh, das übrige Asien 27.000 TWh und Europa 2.400 TWh). In Verbindung mit der geografischen Nähe und seinem enormen technischen Potenzial ist Afrika eine naheliegende Option um den Wasserstoffbedarf Europas und Deutschlands zu decken

Das Thema Wasserstoff wird in Deutschland durch die Nationale Wasserstoffstrategie der Bundesregierung von 2020 geprägt. Im Export-Import-Kontext sind auch das deutsche Gesetz über die unternehmerischen Sorgfaltspflichten zur Vermeidung von Menschenrechtsverletzungen in Lieferketten (*Lieferkettensorgfaltspflichtengesetz* – LkSG) und die Wasserstoffkriterien des Nationalen Wasserstoffrats von besonderer Bedeutung.

# 4 Wasserstoffpolitik in Deutschland und der EU

## Deutschland

Die neue deutsche Regierungskoalition aus SPD, Bündnis 90/Die Grünen und FDP (seit 2021) hat kürzlich das Wasserstoff-Ziel der früheren Regierungskoalition unter Angela Merkel verdoppelt. So sollen bis 2030 statt 5 GW Wasserstoff-Elektrolyseur-Kapazität 10 GW installiert werden (Radowitz, 2021). Diese Aktualisierung wird in eine Überarbeitung der bestehenden *Nationalen Wasserstoffstrategie* (NWS) eingebettet, die 2020 verabschiedet wurde. Es ist darauf hinzuweisen, dass diese Strategie bereits qualitative Anforderungen und Kriterien für Wasserstoffimporte enthält. Insbesondere wird der Grundsatz aufgestellt, dass jeder Import von grünem Wasserstoff oder seinen Derivaten zusätzlich zur inländischen Energieerzeugung erfolgen muss ("Zusätzlichkeitsprinzip"). Dieses Kriterium ist von grundlegender Bedeutung für die Bewältigung einiger der wichtigsten wirtschaftlichen und ökologischen Herausforderungen im Zusammenhang mit der Wasserstofferzeugung.

Das Hauptinstrument der deutschen Außenwirtschaftspolitik im Bereich Wasserstoff sind bilaterale Partnerschaften im Energiesektor (NWS-Maßnahmen 34 und 36). Bilaterale Energiepartnerschaften sollen "den hochrangigen zwischenstaatlichen Dialog mit praktischer, zielorientierter Projektarbeit zusammenführen" (GIZ, 2021a) und dabei über den Energiebereich hinausgehen und die länderspezifischen Prioritäten berücksichtigen. Deutschland unterhält eine Reihe solcher Energiepartnerschaften, darunter acht Kooperationen, die sich speziell mit Wasserstoff befassen (Dietz-Polte & Vacha, 2021; GIZ, 2021a). Diese Partnerschaften bestehen sowohl mit Ländern des Globalen Nordens als auch mit Ländern des Globalen Südens. Drei dieser Kooperationen bauen auf bestehenden bilateralen Energiepartnerschaften auf (Chile, Marokko, Südafrika). Darüber hinaus wurden Wasserstoffpartnerschaften mit Australien, Kanada, Japan, Namibia und Saudi-Arabien geschlossen.

Generell soll das neue deutsche *Lieferkettensorgfaltspflichtengesetz* die internationale Menschenrechtssituation verbessern, indem es Verantwortlichkeiten für das Management von Lieferketten definiert. Deutsche Unternehmen müssen sicherstellen, dass sie eine Reihe von Sorgfaltspflichten erfüllen um Menschenrechtsverletzungen zu verhindern (BMWK, 2022). Dazu können auch ökologische und soziale Aspekte gehören. Die Tragweite und Ausgestaltung des Gesetzes wird jedoch erst in der Praxis und in der Rechtsprechung deutlich werden. Neben der Wasserstoffproduktion und den Wasserressourcen könnte es sich auch auf die Beschaffung von spezifischen Metallen beziehen, die für Elektrolyseure benötigt werden (Johann, 2022).

## EU-Ebene

Auch die Europäische Kommission nutzt Energiepartnerschaften und setzt eine "Wasserstoffdiplomatie" um. Darüber hinaus folgt die europäische "Wasserstoffstrategie für ein klimaneutrales Europa" einer ähnlichen Logik wie die des deutschen Ansatzes, wie von Matthes et al. (2021) dargelegt. Zunächst sollen die Grundlagen bis Mitte der 2020er Jahre in Europa geschaffen werden, um dann in den folgenden zwei bis drei Jahrzehnten rasch skalieren zu können.

Auch auf EU-Ebene werden derzeit Kriterien für grünen Wasserstoff festgelegt (Oyarzabal et al., 2022). Im Februar 2022 startete die EU-Kommission die Einrichtung einer EU-weiten Datenbank, um den Kohlenstoff-Fußabdruck von Wasserstoff – der derzeit zu 96 % aus fossilen Brennstoffen besteht – und anderen so genannten "kohlenstoffarmen" Brennstoffen auf harmonisierte Weise zu zertifizieren (Kurmayer, 2021). Die EU geht davon aus, dass bis 2050 fast ein Viertel des weltweiten Energiebedarfs durch grünen Wasserstoff gedeckt wird und damit eine Schlüsselrolle bei der Erreichung ihrer eigenen Klimaziele spielt (EC, 2020). Ein wichtiger Schritt zur Umsetzung der EU-Wasserstoffstrategie war das Legislativpaket zu Wasserstoff und dekarbonisierten Märkten im Dezember 2021, das derzeit (Stand: März 2022) noch überarbeitet wird. In dem Legislativpaket werden auch neue Regeln für die Entwicklung eines Wasserstoffmarktes in der EU vorgeschlagen. Diese bringen rechtliche Klarheit in Bezug auf die Definition und die Rolle von grünem und kohlenstoffarmem Wasserstoff in der EU.

Es ist absehbar, dass auch auf europäischer Ebene ein Lieferkettengesetz verabschiedet wird. Nichtregierungsorganisationen (NGOs) und andere politische Akteure werden höchstwahrscheinlich auch auf EU-Ebene für die Sorgfaltspflicht für Lieferketten als Kläger auftreten können, da jedes EU-Land die EU-Richtlinien in nationales Recht umsetzen muss.

## Vorhersehbare Folgen einer ungebremsten Wasserstoffwirtschaft

Richtig angegangen, bietet die Versorgungslücke für Wasserstoff eine bedeutende Entwicklungschance für die Länder des Globalen Südens und insbesondere für Afrika, indem sie den lokalen Bedarf decken, Arbeitsplätze schaffen und kontinuierliche Einnahmen aus der Teilnahme an den Energiemärkten als Exporteure erzielen. Große Investitionsprojekte im Globalen Süden, insbesondere mit Exportorientierung zur Versorgung des Globalen Nordens mit Grundstoffen, erinnern jedoch an ausbeuterische Wirtschaftsbeziehungen und Praktiken aus der Kolonialzeit und des Öl-Zeitalters. Solche Entwicklungen gilt es zu vermeiden.

Die Ausweitung der Wasserstoffproduktion kann bestehende oder neue Praktiken des "wirtschaftlichen Kolonialismus" fortsetzen, selbst unter dem Deckmantel der "Umweltfreundlichkeit", und damit ein Muster fortsetzen, bei dem das Überleben und die Sicherheit derjenigen, die innerhalb der westlichen Grenzen leben, über die Bedürfnisse derjenigen gestellt werden, die außerhalb dieser Grenzen leben. Insbesondere besteht die

Gefahr, dass die Wasserstoffproduktionskapazitäten auf Kosten der nationalen Bemühungen zur Erreichung nationaler Entwicklungsziele, einschließlich der Klimaneutralität, oder der Bereitstellung grundlegender Dienstleistungen wie Strom- oder Wasserversorgung gehen.

Unter anderem betont van de Graaf, dass der "Wasserstoff-Hype" das Ergebnis der Erwartung ist, dass Wasserstoff "der nächste große Preis werden könnte, eine kohlenstofffreie Version von Öl" (Van de Graaf, 2021; p. 30). Andererseits scheint der Aufbau einer Infrastruktur für den Wasserstofftransport entlang etablierter Handelsrouten einfacher und kostengünstiger zu sein, weshalb die bisherigen Gewinner der Globalisierung auch in der Pole-Position sind, um auch die Gewinner einer neuen "Wasserstoffwirtschaft" zu werden, unabhängig von ihren Standortfaktoren (Wasser, erneuerbare Energie, Investitionskapital). In diesem Sinne und entsprechend der Definition von Adoko et al. (2021, p. 196) können neokoloniale Strukturen in der Wasserstoffwirtschaft auch durch die Vernachlässigung der Einbeziehung Afrikas in die Wirtschafts- und Entwicklungschancen, die sich aus der neuen Technologie ergeben, entstehen. Daher ist es wichtig, dass Länder des Globalen Südens Wasserstoffproduktionskapazitäten sowohl für den Eigenbedarf als auch für den Export aufbauen und damit ihre derzeitige Abhängigkeit von fossilen Energieträgern und die entsprechenden Strukturen überwinden. Der Export von Wasserstoff in Länder des Globalen Nordens sollte dabei an Kriterien geknüpft sein, die eine Ausrichtung an den Zielen für nachhaltige Entwicklung und die Maximierung des lokalen Nutzens aus dem Einsatz dieser neuen Technologien gewährleisten.

# 5 Fallstudien

Um sowohl die Möglichkeiten als auch das Potenzial der Produktion und des Exports von "fairem grünen Wasserstoff" als auch die zahlreichen Herausforderungen bei der schnellen Ausweitung der Produktion von grünem Wasserstoff auf dem afrikanischen Kontinent aufzuzeigen, wurden drei Fallstudien durchgeführt: für Marokko, Niger und Senegal. Niger ist ein gutes Beispiel für ein Binnenland, das mit seinen ariden Bedingungen typisch für eine Vielzahl von afrikanischen Staaten ist. Binnenländer (wie Niger) stehen bezüglich der Export-Logistik und den Transportwegen vor anderen Herausforderungen als Küstenstaaten. Als trockenes Land ist die Verfügbarkeit von Wasser eine zusätzliche Herausforderung bei der Produktion von Wasserstoff. Raum- und Landnutzungsfragen hingegen spielen eine eher untergeordnete Rolle, da die Bevölkerungs- und Siedlungsdichte naturgemäß geringer oder nur auf kleine Landesteile beschränkt ist. Auch der Senegal als Küstenstaat mit geringerer Flächenverfügbarkeit, aber mit einem derzeit stattfindenden Boom fossiler Energieträger, steht prototypisch für eine Vielzahl afrikanischer Staaten. Marokko als Flächenland mit einem beträchtlichen Vorsprung in der Solartechnologie gilt als Vorreiter für eine afrikanische Wasserstoffwirtschaft – Mitte Februar 2022 stellte die EU Pläne für Investitionen in Höhe von 1,6 Mrd. EUR in Marokko vor, die Teil des 300 Mrd. EUR umfassenden EU-Infrastrukturplans

"Global Gateway" sind, Europas erstem afrikanischen Projekt und Antwort auf Chinas Belt and Road Initiative (DW, 2022).

Alle drei Fallstudien zeigen, dass ökologische Faktoren und soziale Belange den Ausbau der grünen Wasserstoffinfrastruktur begrenzen werden, sofern die Regierung sie berücksichtigen. Auch infrastrukturelle Fragen sind eine Hürde. Insbesondere der Bedarf an Entsalzungsanlagen und die sichere Entsorgung ihrer Abfälle sind eine Herausforderung. Um sicherzustellen, dass die örtliche Bevölkerung sowohl direkt von den (neuen) Entsalzungsanlagen als auch wirtschaftlich profitiert, sind jedoch zusätzliche Maßnahmen erforderlich.

Die Produktion von grünem Wasserstoff in Niger ist im Vergleich zu anderen Standorten in Afrika schwieriger, aber nicht unmöglich. Es gibt derzeit keinen Anlass zu der Annahme, dass grüner Wasserstoff in Niger in naher oder mittlerer Zukunft auf "faire" Weise hergestellt oder problemlos entweder nach Süden nach Nigeria oder nach Norden nach Algerien und dann weiter nach Europa transportiert werden könnte. Sollte sich das Land entscheiden – und dafür könnte es gute Gründe geben – in Wasserstoffproduktionsanlagen zu investieren, müssen zunächst wichtige Fragen der infrastrukturellen Anbindung und der Wasserverfügbarkeit geklärt werden.

Auch im Senegal liegt der Fokus derzeit auf den "Vorteilen" von Gas und Öl und nicht auf Wasserstoff. Es muss verhindert werden, dass (grüner) Wasserstoff dem Wirtschaftsmodell der "Enklavenproduktion", d.h. Förderung und alleiniger Export, folgt. Große Bevölkerungsgruppen profitieren bislang kaum von den riesigen natürlichen Ressourcen des Küstenlandes.

Damit eine Wasserstoffproduktion in Afrika nicht das bekannte extraktivistische Muster fortschreibt und die damit verbundenen Nachteile weiter festschreibt, ist die Etablierung und Anwendung sozial und ökologisch gerechter Kriterien unumgänglich.

# 6 Kriterien für fairen und grünen Wasserstoff

Die bisherige Diskussion macht deutlich, dass die Wasserstoffproduktion nicht auf Kosten der Entwicklung des Landes gehen darf, sie darf den Globalen Süden nicht ausschließen. Wenn der Globale Süden in die Wasserstoffproduktion eingebunden wird, muss dies auf Augenhöhe geschehen. Die Entwicklung der Wasserstoffproduktion in den Ländern des Globalen Südens muss deren (energetische) Unabhängigkeit und eigene Kapazitäten unterstützen. Das bedeutet, dass es neben der "grünen" Dimension des Wasserstoffs eine weitere Dimension gibt, die sich auf Fairness und soziale Nachhaltigkeit bezieht, und die berücksichtigt werden muss. Die zur Umsetzung des Export/Importverhältnisses entstehenden Beziehungen und Partnerschaften sollten politisch (1) auf der Fähigkeit eines Exportlandes basieren, Investitionsströme und Entwicklungsdialoge auf allen Ebenen (international, national, lokal) zu steuern, um historische oder konventionelle Machtverhältnisse zu überwinden,

(2) Kompetenz- und Fähigkeitstransfer beinhalten, (3) die Schaffung wirtschaftlicher Möglichkeiten im Exportland zum Ziel haben, (4) faire Preise (für den verkauften Wasserstoff) sowie für die Produktionskomponenten anstreben und (5) Unabhängigkeit oder Diversifizierungsmöglichkeiten für Exportländer (keine Exklusivrechte für Importländer) ermöglichen. Darüber hinaus sollte die Zusammenarbeit aus wirtschaftlicher Sicht so gestaltet werden, dass ausbeuterische Strukturen verhindert werden und die Interessen ausländischer Wirtschaftsakteure nicht zu Lasten der lokalen Bevölkerung und ihrer Bedürfnisse gehen. Ein großer Teil der Wertschöpfungskette von Wasserstoffproduktionskapazitäten sollte bereits in der Bauphase lokal stattfinden und in Kooperation mit lokalen und regionalen Wirtschaftsakteuren erfolgen.

Um die Umsetzung dieser Leitprinzipien zu gewährleisten, sollte der oben beschriebene Grundsatz der Zusätzlichkeit zu etwas erweitert werden, das man als „Zusätzlichkeit 2.0“ bezeichnen könnte. „Zusätzlichkeit 2.0“ umschreibt begleitende Maßnahmen, die gewährleisten sollen, dass der Aufbau einer Wasserstoff-Exportinfrastruktur nicht nur die Entwicklung der Exportländer nicht behindert, sondern einen Zusatznutzen für die Lieferländer garantiert. Solche begleitenden Maßnahmen könnten etwa zusätzliche Investitionen in Ökostromanlagen und entsprechender Infrastruktur vor Ort sein, und zwar in einem relevanten Maßstab zusätzlich zu jenen Wind- oder Photovoltaik-Anlagen hinzu, die für die Elektrolyse selbst benötigt werden. Diese würden eine entsprechend ausgedehnte Flächen- und Wasserverfügbarkeit sowie das Vermeiden von Nutzungskonflikten mit der heimischen Bevölkerung und der Biodiversität voraussetzen. Damit geht das Prinzip der „Zusätzlichkeit 2.0“ über einen reinen „do no harm“-Ansatz hinaus, und fordert für Wasserstoffprojekte "+X-Lösungen".

Auf dieser Grundlage schlägt die Studie vierzehn Kriterien vor, die auf vier übergreifenden Dimensionen basieren: Soziales, Ökologie, Wirtschaft und Politik. So soll sichergestellt werden, dass bereits bei der Planung oder Diskussion von Wasserstoffprojekten in Afrika die richtigen Fragen gestellt werden können.

# 7 Anforderungen an die Umsetzung

Die sofortige Umsetzung des gesamten Kriterienkatalogs ist natürlich nicht realisierbar. Eine sukzessive Umsetzung und die Implementierung in bereits bestehende politische Prozesse und Regelungen erfordert in den Bereichen Infrastruktur, Energiekapazität, Finanzierung und Institutionen bestimmte Entwicklungen und Maßnahmen.

### Infrastruktur

Die Teilnahme an der globalen Wasserstoffwirtschaft kann auch Ländern, die derzeit weniger entwickelt sind, neue Entwicklungsmöglichkeiten eröffnen. Der infrastrukturelle "Brückenschlag" nach Afrika muss von Europa aus begonnen und weitgehend finanziert werden. Neben dem Kostenaspekt müssen auch geopolitische und entwicklungspolitische Überlegungen bei der Planung der Infrastruktur berücksichtigt werden. Dies gilt ausdrücklich auch für die länderübergreifende Planung der einzelnen Komponenten der Wasserstoffproduktionskette (Elektrolyseure, Strom, Wasser).

Da der Aufbau der entsprechenden Infrastruktur komplex, kostenintensiv und langwierig ist (sowohl in Afrika als auch auf der Importseite in Deutschland und Europa) und hier entsprechende Pfadabhängigkeiten entstehen werden, ist es ratsam, die Infrastruktur nicht auf „dual use" auszurichten, also seitens der Lieferländer nicht auf fossile Exporte und auf Wasserstoff zugleich, sondern den fraglichen Infrastrukturaufbau klar auf Wasserstoff zu fokussieren.

Anders als im europäischen oder osteuropäischen Kontext kann im afrikanischen Kontext kaum auf bereits bestehende Energie-Infrastrukturen zurückgegriffen werden (die im Zweifelsfall noch an Wasserstoff angepasst werden müssten). Dies eröffnet die Chance, in Zusammenarbeit mit den afrikanischen Partnerländern sinnvolle und optimale Lösungen für die Logistik neu zu gestalten, ohne bereits bestehende Einschränkungen oder Pfadabhängigkeiten berücksichtigen zu müssen. Von deutscher Seite sollte dieser Prozess über die EU bzw. in enger Abstimmung mit der EU angegangen werden.

## Aufbau von Energiekapazitäten

Im Prinzip gibt es in allen westafrikanischen Ländern ein großes Potenzial an erneuerbaren Energien. Allerdings muss der für die Wasserstoffproduktion notwendigen erneuerbaren Strom zusätzlich zum Eigenbedarf des Landes generiert und zur Verfügung gestellt werden. In den Fallstudien zu Senegal und Niger wurde deutlich, dass diese Länder noch sehr geringe Erneuerbare Energien-Quoten in ihrem Strommix haben. Die Erzeugung von Wasserstoff aus Netzstrom würde nicht nur die Verfügbarkeit dieses Stroms für andere Zwecke verringern, sondern auch nicht zu "grünem" Wasserstoff führen. Hier sind ehrgeizige politische Strategien für den Ausbau der erneuerbaren Energien und des Stromnetzes gefragt, die mit rechtsverbindlichen Verträgen mit den Entwicklern und Geldgebern dieser Infrastruktur abgesichert sein sollten.

Die zusätzlichen Kapazitäten an erneuerbarem Strom sollten parallel zum notwendigen Ausbau des Energiesystems entwickelt werden, mit direktem Anschluss an das bestehende nationale oder regionale Stromnetz oder netzunabhängig. In allen Fällen ist es wichtig, dass die beteiligten Partnerländer bzw. Projektakteure (Wirtschaftsunternehmen etc.), zivilgesellschaftliche Akteure und Betroffene gemeinsam länderspezifische Lösungen finden und diese dann angepasst an die jeweiligen Gegebenheiten umsetzen. Für die Wasserstoffproduktion ist eine kontinuierliche und störungsfreie Verfügbarkeit von Energie wichtig, weshalb bei der Nutzung von Wind- und Sonnenenergie entsprechende Batterie- oder Speichersysteme eingeplant werden müssen. Die Einbindung in das bestehende Stromnetz könnte Vorteile für den lokalen Netzbetrieb bringen.

Darüber hinaus sollte der Aufbau von Know-how und Kapazitäten vor Ort in den entsprechenden Bereichen integraler Bestandteil jeder Wasserstoffpartnerschaft sein. Die Etablierung der Wasserstoffproduktion und der damit verbundene Ausbau der erneuerbaren Energien kann hierfür ein Türöffner sein und entsprechende nachhaltige Geschäftsfelder und Entwicklungschancen eröffnen.

**Finanzierung**

Deutschland verfügt über eine Reihe von Möglichkeiten zur Finanzierung solcher Projekte. Dazu gehören eine eigene *Förderrichtlinie für internationale Wasserstoffprojekte im Rahmen der Nationalen Wasserstoffstrategie und des Konjunkturprogramms* (BMWK, 2021b), Deutsche Exportkreditgarantien, KfW-Darlehen oder die Deutsche Investitions- und Entwicklungsgesellschaft (DEG) als Projektfinanzierung an den privaten Sektor.

Darüber hinaus ist eine indirekte Finanzierung von Wasserstofferzeugungsprojekten über das innovative Förderinstrument H2Global möglich. Für dieses Instrument wurden vom Bundesministerium für Wirtschaft und Klimaschutz bis Ende 2021 900 Millionen Euro bewilligt. Der Ansatz dieses Instruments besteht darin, dass grüner Wasserstoff oder seine Derivate über einen Zwischenhändler zum entsprechend hohen Preis eingekauft und dann zu einem niedrigeren Marktpreis (im Wettbewerb mit anderen Wasserstoffarten) verkauft werden und die Preisdifferenz zwischen grünem und grauem Wasserstoff durch Zuschüsse des Bundes gedeckt wird (H2international, 2021).

Es wäre eine Überlegung wert, diesen Ansatz auf einzelne Länder oder Ländergruppen (z. B. Westafrika) zu fokussieren, um die Entwicklung der Wasserstoffproduktion in diesen Regionen gezielt zu fördern.

**Aufbau von Institutionen**

Vor allem aber muss der Kriterienkatalog für fairen grünen Wasserstoff sowohl in Deutschland und Europa als auch im Partnerland gesetzlich verankert und umgesetzt werden. Die Diskussionen und Erkenntnisse müssen in die entsprechenden politischen Prozesse eingespeist werden, um Planungs- und Handlungssicherheit für alle beteiligten Akteure zu schaffen. Auf deutscher Seite finden sich erste Ansätze dazu beispielsweise in der Förderrichtlinie für internationale Wasserstoffprojekte oder im Lieferkettensorgfaltspflichtengesetz, entscheidende Kriterien sind jedoch nicht ausreichend formuliert und müssen durch Rechtsprechung konkretisiert werden. Hier kann durch Unterstützung für (afrikanische) NGOs dafür gesorgt werden, dass fragliche Punkte durch Rechtsprechung konkretisiert wird.

Weitere Voraussetzungen betreffen die Bereiche Forschung und Ausbildung von Fachkräften, u.a. durch breit angelegte Austauschprogramme in den relevanten Disziplinen, die Sensibilisierung potenzieller Partner für das Potenzial von Wasserstoffpartnerschaften und die

Vorstellung der Möglichkeiten und Vorteile der Produktion von grünem und fairem Wasserstoff im politischen und öffentlichen Diskurs. Auch eine Einbindung und Aufklärung von lokalen NGOs kann hier hilfreich sein. NGOs könnten z. B. ambitioniertere Dekarbonisierungspläne von ihren Regierungen einfordern oder die Option der Produktion von fairem grünem Wasserstoff für ihre Transformation zur Klimaneutralität im jeweiligen nationalen Diskurs prominenter machen.

Festzuhalten ist, dass davon auszugehen ist, dass die enorme Nachfrage nach grünem Wasserstoff sowie die langen Vorlauf- und Aufbauzeiten und die absehbaren hochdynamischen technischen Entwicklungen zu einem Anstieg des Handlungsbedarfs führen werden. Ebenso werden sich Handlungsspielräume und -notwendigkeiten ergeben, die dann politisch gefüllt werden müssen. Es besteht die Gefahr, dass bei solch dynamischen Entwicklungen der Zeitraum für die Entwicklung und Etablierung von Standards verpasst wird und später viele wichtige ökologische und soziale Fragen der Zielerreichung untergeordnet werden. Daher ist es ratsam, so früh wie möglich Kriterien für die Produktion von grünem und fairem Wasserstoff zu formulieren, damit bereits in der jetzt beginnenden Anfangsphase des sich entwickelnden globalen Wasserstoffmarktes die Prozesse und Strukturen entsprechend ausgerichtet werden können. Die entstehenden Pfadabhängigkeiten erfordern ein frühzeitiges Handeln.

# 1 Introduction

In a world where the dooming climate crisis increasingly turns into a planetary crisis, the development of a sustainable and clean 'hydrogen economy' is considered essential if the world wants to keep the hope alive to limit global warming to 1.5°C above pre-industrial levels.[1] Thus, alongside (1) the phase-out of fossil fuels, (2) the development of renewable energy generation and (3) increased energy efficiency, the establishment of (4) a hydrogen infrastructure as an avenue to utilize green electricity in sectors and industries where fossils has been used in material processes up to now (e.g. reduction in steel production), where direct electrification is hardly possible (e.g. air and sea transport), and as a carbon-free energy source in high-temperature processes and for future reconversion to electricity during dark doldrums and as a storage medium is planned.

Many countries strive for 'carbon-neutral'[2] societies and economies - Germany, for example, has set this aim for 2045. As of now, discussions surrounding hydrogen are mostly concerned with the technical aspects of scaling up global green hydrogen production quickly, vastly ignoring the manifold social and ecological challenges coming with this (not so) new energy carrier.

The demand for green hydrogen will grow rapidly by the middle of the century, especially in countries and regions of the Global North such as Germany and Europe. At the same time, however, it is foreseeable that only a few of these countries will be able to meet their own demand for green energy.

In principle, green hydrogen can be produced in many countries and regions of the world. Experts and decision makers see an opportunity for the sun- and wind-rich regions and countries in the Global South[3] to meet the enormous future demand for hydrogen. For example, Germany's former research minister Anja Karliczek, emphasized that West Africa alone has the potential to produce green hydrogen equivalent to 1,500 times Germany's demand in 2030 (*Bundesministerium für Bildung und Forschung* [BMBF], 2021a).

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[1] The Paris Agreement of 2015 states in Art. 2 the aim of "[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change […]." (United Nations Framework Convention on Climate Change [UNFCCC], 2015).

[2] That is, societies and economies not reliant on fossil fuels or only to such a small extent that the remaining sources of climate-damaging greenhouse gases can be stored, compensated for or re-used for industrial processes.

[3] The terms countries of the 'Global South'/'Global North' are preferred over the use of 'developing countries' and 'developed countries' as they are not intended to be judgemental in any way and since there is no one clear-cut distinction between countries in their respective development ambitions and trajectories. The authors are aware of the inadequateness of both terms but, in the absence of better-fitting terms, make use of them throughout the study.

However, the political discourse does not properly reflect that a hydrogen rush can also have negative effects on the countries of the Global South. Satisfying the Global North's demand for water should not come at the ecological, economic, and political expense of the respective countries of the Global South. The risk of 'green colonialism' (Scita et al., 2020) must be considered and taken into account in decision making.

This study looks specifically at the German demand for green hydrogen and asks whether and under what conditions it can be met by imports from the Global South. Can this be done in a both socially and ecologically acceptable way for the countries exporting green hydrogen?[4] As the West Africa region has received some attention by decision makers in Germany, and is considered a potential future export region for green hydrogen (e.g. FZ Jülich, 2022), three case studies in this region are conducted. They illustrate some of the essential challenges for the importation of green hydrogen from the Global South. On this basis the study proposes a catalogue of criteria for the sustainable and fair production and export of green hydrogen. The derived set of criteria, which cover both the 'fair' and the 'green' aspects, enriches the current discourse by a social dimension, in addition to the ecological aspects that have been at the forefront in existing publications (e.g. Bundesregierung, 2020b; Öko-Institut et al., 2021), *Nationaler Wasserstoffrat* [NWR], 2021; *Sachverständigenrat für Umweltfragen* [SRU], 2020).

Germany is in the process of developing a new National Hydrogen Strategy (*Nationale Wasserstoffstrategie* [NWS]) which will be presented in 2022. This study also aims to constructively shape the discourse around this strategy so that it can leverage development opportunities in the countries of the Global South. The study presents concrete action points so that the "missing piece of the clean energy puzzle" (International Renewable Energy Agency [IRENA, 2022a; p. 10) benefits both the countries of the Global North and the Global South.[5]

[4] This study will solely discuss criteria for exporting/importing green hydrogen. Other forms of hydrogen and hydrogen in general are reflected sufficiently elsewhere (e.g. Bundesregierung, 2020; Öko-Institut et al., 2021).

[5] Though profiting the latter more, both in relative and absolute terms, considering, among others, the historical injustices regarding contributions to the climate crisis (disproportionately by the Global North) and the ongoing failure of industrialised countries to significantly increase their climate protection targets (e.g. Climate Action Tracker [CAT] 2022).

# 2 Hydrogen – the technical dimension

This chapter discusses some of the technological requirements for producing green hydrogen to provide a foundational understanding of the interplay of technical, social, and ecological aspects of hydrogen as a resource and energy carrier. The chapter discusses the main input factors for the production of green hydrogen – the production technology, renewable electricity and water – and transport options.[6]

**Box 1: Hydrogen**

| |
|---|
| The first element of the periodic table, hydrogen is a highly reactive colorless gas. In contact with oxygen, it is unstable which is the reason why there are no harvestable natural resources. In technical systems, hydrogen is both an energy carrier and a resource. Hydrogen can be produced from electricity and water, and its climate impact depends on the source for this power. |

## 2.1 Hydrogen of different colors

Green hydrogen is particularly important for the de-fossilization of sectors and industries that use carbon-based materials for the reduction of oxides (e.g., production of steel). It can also be used for many other purposes but due to its high costs should be utilized only in those applications for which no other clean technologies are available (e.g., selected transport technologies, selected high temperature processes or specific electricity storage situations).

The production of hydrogen is (currently) extremely expensive, recommending it for the title of the 'champaign of energy transition'. The main reason for that is that some of the technologies for producing and transporting hydrogen are not yet fully commercially available, have high conversion losses and/or come with other downsides to it (see Box 2). It will take time until economies of scale and scope can lead to mass-manufactured components. Until that time, the discussion around the decarbonization strategies will need to keep in mind that for most sectors – specifically for the vehicle and heat sectors -, direct electrification is the faster and more realistic strategy.

[6] Transport options are the same for all kinds of hydrogen.

**Box 2: The color spectrum of hydrogen.**

Hydrogen can be produced with different processes. Depending on the process, its production might be fraught with carbon emissions. Others required highly energy intensive and contested technologies for carbon sequestration and storage. In order to classify the various processes and energy sources for the production of hydrogen, a spectrum of nine different hydrogen 'colors' has been established in the political discourse:

| Color | Description |
|---|---|
| Green | Produced from renewable energy sources with zero carbon dioxide ($CO_2$) emissions via water electrolysis |
| White | Hydrogen in its (rare) natural form or as by-product of industrial processes with zero to relatively little $CO_2$ emissions |
| Pink* | Produced from nuclear power via water electrolysis |
| Red* | Produced from biomass gasification with $CO_2$ emissions commensurate with the carbon content of the biomass, could be coupled with carbon capture and storage technologies are deployed |
| Yellow* | Produced from mixed sources via water electrolysis, with varying amounts of $CO_2$ emissions |
| Turquoise | Produced as by-product of methane pyrolysis, together with solid carbon, with $CO_2$ emissions mostly dependent on the electricity mix[7] |
| Blue | Produced from fossil fuels where $CO_2$ from production processes is stored, captured, and stored or repurposed |
| Grey* | Produced from natural gas with relatively high $CO_2$ emissions by stream reforming[8] or electrolysis. |
| Brown | Produced from coal gasification with relatively high $CO_2$ emissions[9] |

Source: Eversheds Sutherland (2021).

For the colors with * sometimes, other definitions are also used. The following types of hydrogen are most prominent in the current discourse (Eversheds Sutherland, 2021):

1. As of now, **grey hydrogen** is by far, the most widespread form of hydrogen. It is produced by steam reforming of methane. **Brown hydrogen** is produced with the same process but based on coal instead of methane. The carbon dioxide emitted in this process is released into the atmosphere. This and the associated energy consumption lead to a significant carbon dioxide footprint of grey hydrogen, and thus useless as a decarbonization agent.

2. **Blue hydrogen** is produced like grey hydrogen but major parts of the carbon dioxide from the production are captured and stored. The storage must ensure that the carbon dioxide cannot be released back into the atmosphere. Yet, blue hydrogen will still be associated with carbon emission, from methane production as well as

[7] Not yet commercially deployable (Eversheds Sutherland, 2021).
[8] The most common form of producing hydrogen as of now (Eversheds Sutherland, 2021).
[9] The second-most common form of producing hydrogen as of now (Eversheds Sutherland, 2021).

the generation of the electricity used in the steam reforming process. Carbon emissions can therefore be reduced in blue hydrogen production, but cannot be fully eliminated (IRENA, 2020a). In addition, underground storage is controversial.

3. **Turquoise hydrogen** is still in the pilot phase. It is produced by pyrolysis which extracts hydrogen from fossil methane, leaving behind a solid block of carbon. Emissions of methane production and power generation still arise.
4. **Green hydrogen** is produced with renewable electricity, by electrolysis of water into hydrogen and oxygen and using renewable electricity, avoiding greenhouse gas emissions.

Grey hydrogen, produced by steam-reforming from natural gas, causes about 830 Mt of carbon dioxide emissions per year, equivalent to combined emissions of the United Kingdom and Indonesia (IEA, 2019). This study's focus is on green hydrogen, based on renewable electricity, since other processes for the production of hydrogen such as those based on natural gas by steam reforming or pyrolysis cannot be considered compatible with the commitments of the global community to fast decarbonization: They are either not yet commercially deployable (turquoise hydrogen), are reliant on energy technologies that come with severe security risks (pink hydrogen) or are dependent on fossil fuels (yellow, blue and brown hydrogen). Red and white hydrogen could be argued to be associated with low carbon emissions under specific conditions (e.g. if a feasible solution for carbon sequestration is found, if biomass is produced in low carbon agriculture, etc.), but as of 2022 play hardly any role (Hydrogen Europe, 2022; World Economic Forum, 2021).[10]

[10] In fact, both sources use the label 'red hydrogen' not for biomass gasification but for another, nuclear-related process.

## 2.2 Electrolysers

The electrolysis of water (Fraunhofer ISI et al., 2019) has been known and used since the 19th century (International Energy Agency [IEA], 2019). This electrochemical process splits water into hydrogen and oxygen. The appliance in which this happens is called electrolyser, and the process requires water as well as electricity.

The three main electrolyser technologies today are alkaline electrolysis, proton exchange membrane (PEM) electrolysis, and solid oxide electrolysis cells (SOEC). Alkaline electrolysers have relatively low investment costs compared to other electrolysers as the technology is more or less mature. Their disadvantage is that they use potassium hydroxide as the electrolyte rather than pure water, which requires an additional production step for the recovery and recycling of the potassium hydroxide electrolyte solution. PEM electrolysis can use pure water as electrolyte but has a lower efficiency and higher costs. The SOEC electrolyser has the best electrical efficiency of the three, but also the highest investment costs, and is dependent on a heat source since steam is used as the electrolyte (IEA, 2019).

The following development of electrolyser technology is expected:

- the first stage is characterized by few manufacturers with small plants (1-100 megawatt [MW]);
- In a second phase, a diversification of players and higher growth rates of 0.1-5 gigawatt (GW) production capacity/year (a) will take place;
- The last stage is marked by a competitive environment with growth rates up to 5-10 GW production capacity/a.

The transition from the first to the second phase is characterized by the fact that more and more smaller electrolyser modules are combined to form an overall larger production unit. In the transition from stage 2 to stage 3, the size of the individual modules will increase and their production will be successively optimized (Matthes et al., 2021).

## 2.3 Water Supply

Electrolysers require freshwater for hydrogen production. About 0,27 liter (l) of water are needed to produce one kilowatt hour (kWh) hydrogen alone (IEA, 2019).[11] Thus, 89 billion[12] (bn) l/a (88,290,000 cubic meters [m$^3$) of water would be necessary to produce the amount of green hydrogen imports needed in Germany by 2045 according to (Prognos et al., 2021). For comparison: The German freshwater consumption in private households in 2016 was more

[11] According to IEA (2019): 9 l for 1 kilogram (kg) hydrogen corresponds to 9 l for 33 kWh hydrogen, so 0.27 l are needed for 1 kWh.

[12] Beyond American and British English, the number 1,000,000,000 is known as ‘Milliarde’ in German and French.

than forty times as much. IRENA assumes that the global hydrogen production in 2050 will still require less than 1 % of today's water needs for irrigation, and only about 2/3 of today's desalination capacity (IRENA, 2022; p.98).

Thus, in non-arid regions and countries such as Germany the amount of freshwater needed for hydrogen is unlikely to be noticed (Umweltbundesamt 2020). But in arid regions such as in large parts of Africa, there is a much higher risk that such water demand will exacerbate existing water conflicts or generate new ones, given the scarcity of water. According to World Bank statistics, Sub-Saharan Africa has a renewable internal freshwater resource of approximately 3,844 bn $m^3$.[13] But for example, Niger has only 3.5 bn $m^3$ of freshwater resources, Senegal 25.8 bn $m^3$ and Nigeria 221 bn $m^3$.

In order to avoid additional stress on water supplies in water-scarce areas, the use of seawater is considered as an alternative. For use in an electrolyser, this water must first be treated in desalination plants. Using reverse osmosis for desalination requires 3-4 kWh of electricity per $m^3$ of water, so that the energy demand for that will have only a small impact on the total cost (IEA, 2019).[14] But there are additional challenges associated with desalination, including investment costs, more land use through renewable energies, siting and disposal of brines. Transporting fresh water to the hydrogen production sites via pipelines is also a conceivable alternative, and its economic benefit must be assessed on a case-by-case basis.

In countries where fresh water is scarce and water stress is already high, additional consumption of available water can exacerbate existing problems around competing water uses. At the same time, however, it is also possible that the establishment of a hydrogen production chain will improve the water situation in the regions concerned. This can happen through the construction of desalination plants which cover more than the needs of the electrolyser, and correspondingly supply fresh water for other uses. It is also conceivable that the development of renewable energies necessary for the production of green hydrogen and the simultaneous reduction of fossil energy production technologies (especially coal and gas), which consume large amounts of water, can save water and use it in other ways (SRU, 2020; p. 29).

## 2.4 Renewable Electricity Supply

It is tempting to place electrolysers close to water supplies and provide the electricity through a national power grid. However, without any control for the green quality of the electricity, the hydrogen production might emit more carbon dioxide than the direct burning of fossil

[13] For comparison, the European Union has a renewable internal freshwater resource of approximately 1360 bn $m^3$.

[14] According to IRENA (2022a) desalination for green hydrogen only adds about 1–2 % to energy consumption and the cost of production, where the electricity consumed is the determining factor.

fuels. Öko-Institut (2019) claims that this can only be excluded if the share of green power on the grid is higher than 70 %.

Currently, renewable electricity in most situations and countries is typically not yet covering the demand, so that hydrogen production will require additional renewable electricity capacity. These additional renewable energy capacities required for hydrogen production are enormous. For Germany alone, the 169 TWh of imported hydrogen and 158 TWh of imported synthetic fuels ("e-fuels")[15] needed by 2045 would require a combined 327 TWh of electrolysed hydrogen and therefore about 524 TWh of electricity.[16]

Many countries in the Global South have much better solar irradiation values per year than Germany. In sunny areas (with e.g., 2,000 full load hours/a), additional installed photovoltaic capacity of around 262 GW would suffice to cover Germany's import needs (for comparison, Germany today has already 54 GW installed capacity). Using onshore wind energy systems with 3,000 full load hours/a, an installed capacity of 175 GW would be needed to provide the same amount of electricity (compared to Germany's capacity today of 63 GW). But in 2019 the entire African continent had an installed capacity of approximately 7.4 GW of solar energy and 5.8 GW of combined offshore and onshore wind energy (IRENA, 2020c).

## 2.5 Transport Options for the Import of Hydrogen

The three main approaches for transporting hydrogen are by pipeline, ship, or truck. Table 1 provides an overview for these transport options, taking into account use cases as well as the costs and future developments.

There are different kinds of pipeline options for hydrogen transport: Distribution pipelines for local level and transmission pipelines or 'ultra-high-capacity-pipelines' for intercontinental transport. Hydrogen is already transported through hydrogen pipelines in gaseous form over long distances. For example, Air Liquide operates a hydrogen pipeline system with a total length of 966 kilometers (km) in northern France, Belgium, and the Netherlands. Hydrogen can be converted in hydrogen derivates such as liquid organic hydrogen carrier materials (LOHC) or ammonia for pipeline injection. However, this inevitably leads to conversion losses, making the case that conversion of hydrogen should only be an option if it is the most efficient

[15] Also known as "Power-to-Liquid"-fuels, these are kerosene-, petrol- or Diesel-like liquids produced from carbon and hydrogen.

[16] Assuming an electrolysis efficiency of 70 % (Bundesregierung, 2020) for hydrogen, the 169 TWh hydrogen require about 241 $TWh_{el}$ (electrical energy). For the 158 TWh of Power-to-Liquid (PtL), the following is assumed as an example for e-methanol. This also requires hydrogen from water electrolysis (70 % efficiency) as well as methane synthesis and carbon dioxide capture. For the methane synthesis, an efficiency of 80 % and thus a total efficiency of 56 % is estimated (IRENA, 2021). From this, a demand of 198 TWh hydrogen and thus 282 $TWh_{el}$ can be derived. Hydrogen required for transport are missing. Since efficiency losses in transport and the carbon dioxide capture process are not taken into account, the actual requirements are expected to be even higher. These values should only be used for size classification.

transport mode (Buchmann, n.d.). It is also possible to inject hydrogen into natural gas pipelines to some degree. Due to the different pressures on the pipes, special requirements must be observed when changing the operating concept from natural gas to hydrogen (SCI4climate.NRW et al., 2021), and this also constitutes a dilution of the high-value product hydrogen with its raw material natural gas. But from a technical perspective, this is an option (IRENA, 2022a, 2022b).

For transport by ship, hydrogen must be liquefied or compressed. Currently, no ship is available for the commercial transport of compressed gaseous hydrogen. So far, only one prototype for a liquid hydrogen transport ship exists (Lloyd's Register, 2022). For the transport of liquid hydrogen, shipping containers with a capacity of up to 3,000 kg of liquid hydrogen are already used in some cases (SCI4climate.NRW et al., 2021). Alternatively, hydrogen could be transported by ship in the form of ammonia or in LOHCs. These substances are already being transported around the world.

The transport of compressed gaseous hydrogen and hydrogen in containers on trucks or trains is established on the global market. Approximately one ton of compressed gaseous hydrogen can be transported per truck, and for longer distances, 3-4 tons (t) of liquid hydrogen can be transported per truck in the case of liquid hydrogen.[17]

[17] See for many other aspects linked to the transportation of hydrogen Matthes et al. (2021).

Table 1: Overview transport options for the import of hydrogen

| Transport option | Pipeline | Ship | Trucks |
|---|---|---|---|
| **Use cases**[18] | • Requires transport capacities of 10 t hydrogen per day for distribution pipelines and over 100 t hydrogen per day for transmission pipelines<br>• For distances on local level and intercontinental level | • Requires large transport capacities of more than 100 t hydrogen per day<br>• Cost-effective for intercontinental distances of more than 5,000 km | • Most cost-effective option for smaller transport capacities (less than 10 t hydrogen per day)<br>• Suitable for short distances (about 200 km) is hydrogen and liquid hydrogen for longer distances (about 300–400 km) |
| **Costs**[19] | • Transmission level in capital expenditure (CAPEX)/km in US-Dollar (USD) million: for hydrogen USD 1.12 million, for LOHC USD 2.32 million and for ammonia USD 0.55 million<br>• Distribution level CAPEX/km in USD million: for hydrogen USD 0,5 million, for LOHC USD 1 million and for ammonia USD 0.25 million | • CAPEX for hydrogen ship with a capacity of 11,000 t hydrogen: USD 412 million<br>• CAPEX for LOHC ship with a capacity of 110,000 t hydrogen: USD 76 million<br>• CAPEX for Ammonia ship with a capacity of 53,000 t hydrogen: USD 85 million | • CAPEX for hydrogen trailer with a capacity of 0.67 t hydrogen: USD 0.65 million<br>• CAPEX for liquid hydrogen trailer with a capacity of 4.3 t hydrogen: USD 1 million<br>• CAPEX Truck: USD 0.185 million |
| **Future development** | Further infrastructure projects in the field of hydrogen pipelines are currently being driven forward throughout Europe. One example is the port of Rotterdam where the main pipeline for a hydrogen import infrastructure is scheduled to go into operation in 2024/25. | Commercial availability of ships for the transport of compressed gaseous hydrogen is not expected before 2030. Liquid hydrogen carriers will continue to be developed in the coming years. Ships with large transport volumes (more than 10,000 tons) are not expected until mid-2030. | Trucks already offer the possibility of transporting hydrogen. Liquid hydrogen and ammonia could be used to transport ever larger capacities per truck. However, this would require even more liquefaction capacity and ammonia production plants which will not be available on a large scale until 2030. |

Source: Own illustration, based on SCI4climate.NRW et al. (2021), IRENA (2020b) and IEA (2019).

[18] See SCI4climate.NRW et al.(2021, p. 46).
[19] See IEA (2019).

## 2.6 Cost of Hydrogen Production

Costs play an important role in the speed of hydrogen roll-out. While hydrogen is very expensive today, it can be expected to undergo significant cost reduction through learning, economies of scale and scope, but it is not possible to make definitive statements about how quickly this cost reduction will occur. Put quantitatively, organizations such as the Green Hydrogen Catapult[20] aim "to halve the current cost of hydrogen to below USD 2 per kg" and to "accelerate the scale and production of green hydrogen 50-fold" by 2026 (United Nations Framework Convention on Climate Change [UNFCCC], 2020). As current prices for green hydrogen average around 6 USD/kg, both these aims can be considered ambitious (Xue, 2022). But there are even more optimistic assessments. For example, according to the British multinational oil and gas company Shell, the costs for green hydrogen could even fall to as little as 1.40 USD/kg as early as 2030. An important basis for this estimate is the fact that China has prioritized hydrogen (in general) as an emerging industry under its 14th Five-Year Plan, resulting in ever bigger investments by the world's largest producer of hydrogen to reach its net-zero emissions goal by 2060 (Xue, 2022).

## 2.7 Summary

In summary, it will take a significant effort (and time) to build the infrastructure for green hydrogen production facilities. However, the costs of electrolysers are expected to drop rapidly while efficiencies will improve. Further reductions are also expected in the costs for generating renewable electricity, and research is being conducted into the direct use of seawater in electrolysis plants, reducing the operating costs of producing green hydrogen in the future. With regard to the general readiness and availability of the green hydrogen technology, a study by Öko-Institut (2019) assumes that the first large-scale production plants will require at least a planning and construction phase of approximately ten years. The 2020s, however, will proof decisive for the central phase of the market ramp-up for hydrogen: Up to 2035, hydrogen used in Europe will be overwhelmingly produced and transported across the continent; only from the mid-2030s onwards, importing hydrogen from outside Europe per pipeline or ship seems to be any feasible (Öko-Institut 2019).

[20] A coalition constituted by seven self-acclaimed world-leading companies.

# 3 Current and Future Demand for Green Hydrogen

Hydrogen is often discussed as a panacea for the decarbonization of Europe in general and Germany in particular. In 2019, global demand for hydrogen was around 70 megatons/year (Mt/a) (or 2,310 TWh) (Johann, 2022), mainly for use in the chemical industry. In this chapter, we will first explore scenarios for Germany's future green hydrogen demand before we broaden our perspective and look at global green hydrogen demand.

## 3.1 German Green Hydrogen Demand

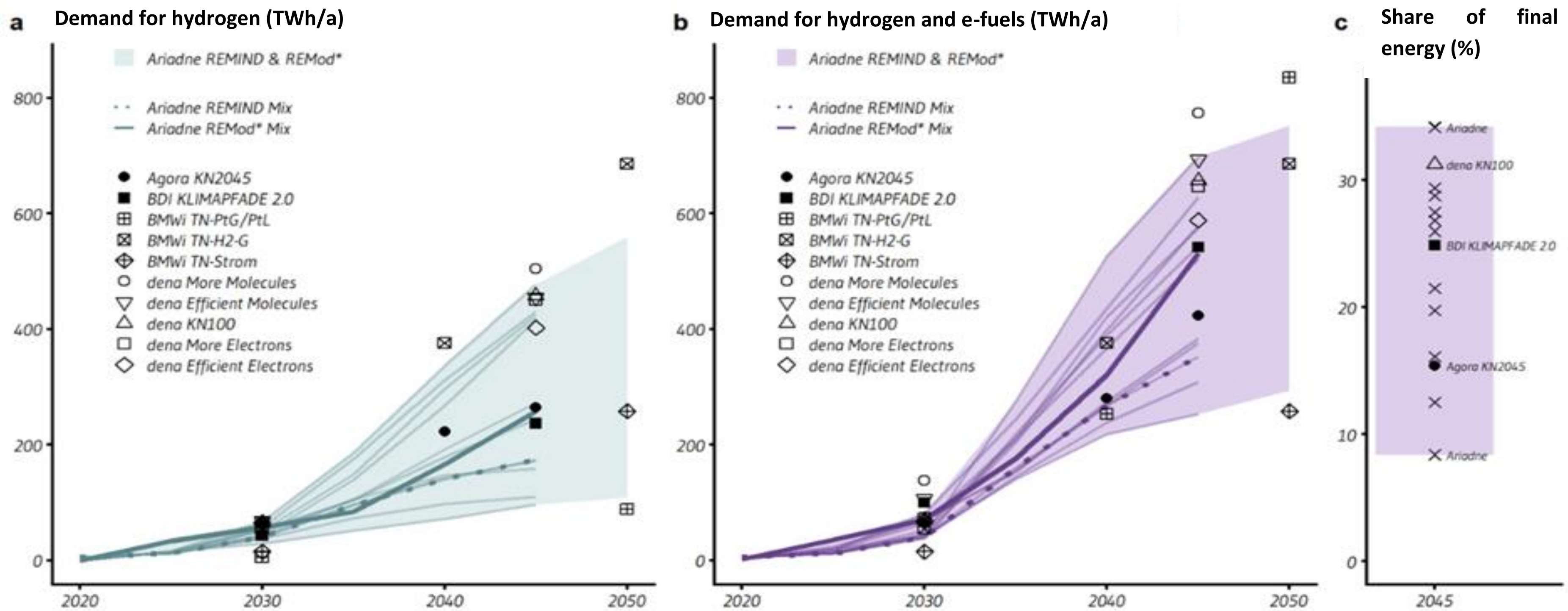
The broad range of demand for green hydrogen and e-fuels in Germany in 2045 is put at 250 TWh to 800 TWh (Ariadne, 2021a). The exact amount of green hydrogen needed depends greatly on a number of very uncertain assumptions. The study *Klimaneutrales Deutschland 2045* ("Climate-neutral Germany 2045"), commissioned by the NGO Agora Energiewende (Prognos et al., 2021), has become a major reference for the German government. According to this study, hydrogen will be used for $CO_2$-free steel production, as a raw material in basic chemistry, to generate process steam, in heavy-duty transport as well as in shipping and aviation (Prognos et al., 2021).

Specifically for green hydrogen, a recently published meta-study by the research consortium Ariadne (Ariadne, 2021b) has received broad attention. It analyses five major studies that forecast the green hydrogen demand for Germany's aim of climate neutrality by 2045 and a total of 22 scenarios (Figure 1).[21]

Initially, roughly until the year 2030, the forecasts for required green hydrogen uniformly predict a rather low demand overall. The reason for this is that all studies assume that hydrogen will continue to be very expensive to generate, compared to natural gas. In 2030, across all scenarios a maximum need of 80 TWh of green hydrogen is predicted due to the challenges and limitations in the market ramp-up (Ariadne, 2021b).

[21] The paths towards climate neutrality in these studies do not build on renunciation or post-growth scenarios as a necessary precondition for climate neutrality. For example, the Prognos et al. (2021) path assumes economic growth of 1.3 %/a. Even if we switch to zero per cent economic growth, the demand for hydrogen for climate neutrality would still be so high that hydrogen imports would be necessary either way.

Figure 1: Demand for hydrogen in Germany




Notes: (a) hydrogen, (b) hydrogen and e-fuels and (c) the final energy share of hydrogen and E-fuels in 2045 from the five current scenario analyses for achieving climate neutrality in Germany.
Source: Ariadne (2021b, p. 11).

In all cases, the projections for future hydrogen demand vary widely. A number of factors explain this wide range. The most important factor is that the different scenarios are based on different assumptions about the energy needs and services for which hydrogen will be used in the future.[22] For many energy needs, technical options exist for using either electricity or hydrogen. As hydrogen is produced from electricity, the option that uses electricity directly always requires much less electricity for the same energy service than the option that uses hydrogen. The reason for this is that energy is lost when electricity is converted to hydrogen and back. However, studies choose different technology mixes, some favoring hydrogen-based options (often in the form of 'e-fuels'[23] for the transport sector), others favoring direct electrification options. Overall, the strategies that rely on large hydrogen amounts, e-fuels (or synfuels) and import, will require much more energy since additional energy will always be required for transport and maybe also conversion.

Scenarios with higher hydrogen consumption assume more hydrogen is imported (in relative and absolute terms). This leads to a situation where 20 % less renewable energy installations will be required within Germany than in scenarios with higher direct electricity uses (Ariadne, 2021b).[24] In addition to hydrogen, these scenarios assume that e-fuels are more likely to be imported rather than produced domestically so that domestic production will not rise as fast. However, to produce e-fuels, production abroad will require many more solar plants and wind farms globally than for scenarios that apply more direct electrification.

Figure 2 shows the demand for green hydrogen and e-fuels (here called power-to-liquid or PtL)[25] by domestic production and imports for the years 2030, 2035, 2040 and 2045 following Prognos et al. (2021). The demand for e-fuels exhibits, a linear increase for the years 2035 and 2040.[26] Imports triple between 2030 and 2035, and then grow slower as domestic production of green electricity is catching up.

[22] In so-called 'direct electrification' scenarios, heat pumps and battery-powered vehicles play a major role, while 'indirect electrification' scenarios place greater emphasis on the widespread use of e-fuels, hydrogen cars and heating systems. Scenarios with higher expectations for 'direct electrification' (i.e., electric vehicles, heat pumps) will calculate lower hydrogen needs and vice versa.

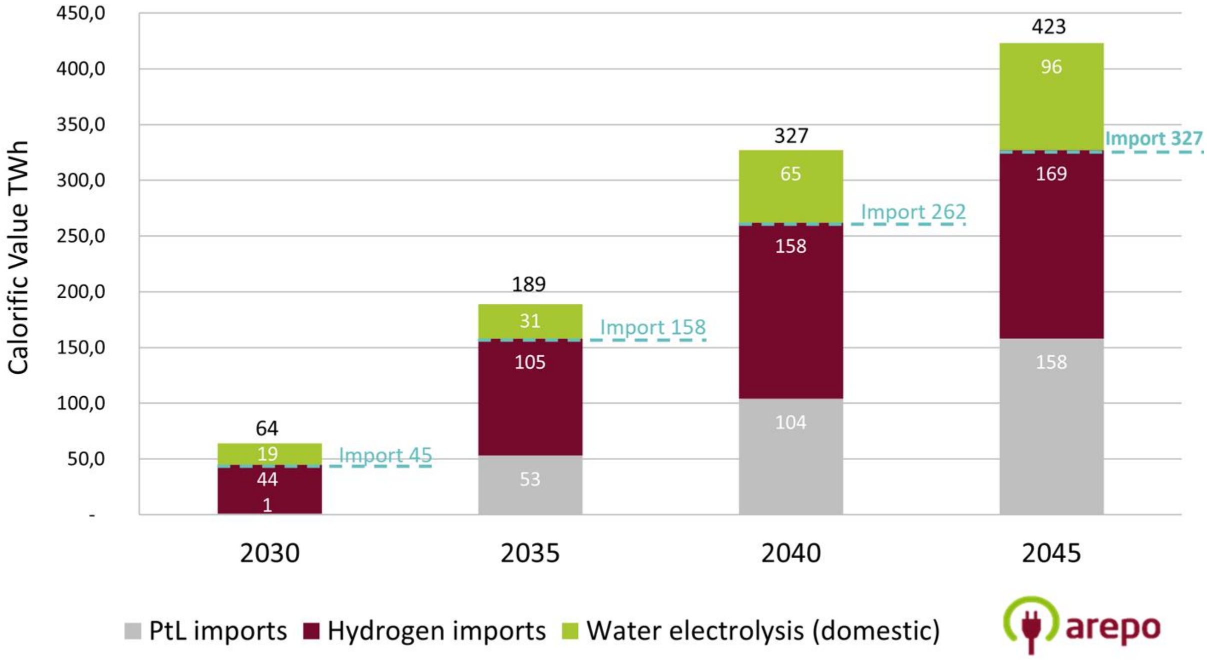
[23] Referring to synthetically produced fuels with the same characteristics as today's mineral oil products, produced from carbon that is captured from the air and hydrogen – a very energy intensive process.

[24] That is, all else being held equal, as renewable energy sources could undoubtedly be used for many other applications.

[25] The concept refers to all conversion of renewable energy to liquid fuels and chemicals such as methanol, oxymethylene ether or ammonia, but often simply kerosene or petrol. They offer high energy density required for aircraft, ships and other applications with a high power demand and the need to serve long distances (Fraunhofer ISE, 2022).

[26] According to Prognos et al. (2021), 1 TWh of PtL is forecasted for 2030 and 158 TWh of PtL in 2045. Assuming a linear expansion of PtL capacities, this results in 53 TWh in 2035 and 104 TWh in 2040. In reality, however, the expansion of PtL capacities will most likely not take place in a linear way but rather in the form of an exponential curve.

Figure 2: Green hydrogen and power-to-liquid deployment according to *Klimaneutrales Deutschland 2045*




Source: Own illustration, based on data from Prognos et al. (2021).

The combined demand for green hydrogen and PtL in 2030 is 64 TWh (Prognos et al., 2021). With a domestic electrolysis production of 19 TWh, 70 % will have to be imported in 2030. For comparison, the National Hydrogen Strategy of the former German government headed by Angela Merkel assumes only 14 TWh of domestic green hydrogen production for 2030 with an installed electrolysis capacity of 5 GW (Bundesregierung, 2020), implying an even higher import need.[27] The new German government coalition headed by Olaf Scholz is planning to renew the hydrogen strategy in 2022 , including a doubling of electrolysis capacity compared to the previous government, to 10 GW in 2030 (Coalition Treaty, 2021), which implies that the domestic production could be as high as 28 TWh, implying a smaller import need.

For 2045, a total demand of 423 TWh of green hydrogen and PtL in Germany has been calculated by Prognos et al. (2021). The scenario assumes that, at that point in time, most hydrogen will be used in power generation. In industry, hydrogen will be mainly used for the direct reduction of iron ore for $CO_2$-free steel production, as a raw material in the chemical industry and for the generation of process steam (Prognos et al., 2021).

In 2045, in addition to hydrogen, e-fuels will be used predominantly in the national and international shipping and aviation sectors. PtL will not be produced in Germany according to this scenario, but imported, totaling about 158 TWh. Taken together, about 77 % (327 TWh) of the 423 TWh need for green hydrogen in Germany in 2045 will be imported (Prognos et al., 2021). By way of comparison: At the global level, IEA assumes that there is

[27] Based on the assumption: 4,000 full load hours and an average efficiency of the electrolysis plants of 70 %.

demand for 70 ExaJoules (EJ) (19,444 TWh) of low-emission hydrogen[28] by 2050 (IEA, 2021b). This comparison highlights on the one hand that there is very large uncertainty in these scenarios, but also that the German projections are on the low side compared to the global expectations for the sector. Germany's share of global hydrogen consumption in 2045/2050 would be around 2.2 %, which is commensurate with its current share of the global GDP of around 3.3 %.

The scenario elaborated here and the German government's National Hydrogen Strategy (Bundesregierung, 2020) make it clear that even if hydrogen is used efficiently and targeted, a considerable amount – consistently around 80 % – of green hydrogen will have to be imported to put Germany on the path to climate neutrality across all sectors. The expansion of renewable energies abroad required for these unprecedented imports of green hydrogen and e-fuel is part of scenarios that aim for direct electrification, i.e. comparatively lower hydrogen demand), with just under 500 TWh (Ariadne, 2021b). This is in the same order of magnitude as Germany's total electricity demand in 2022 (560 TWh) (Agora Energiewende, 2022). Even in a no-growth scenario, a very high share of energy import will be necessary. Germany cannot install enough renewable energy capacity domestically (or only above-average-market prices and with significant conflicts around competing land uses) to meet the projected green hydrogen demand.

This dilemma – Germany cannot install sufficient renewable energy domestically and will depend on other countries to supply its energy needs – highlights drastically how important energy efficiency and conscious use of our resources is for the decarbonization transformation. Independent from the economic argument of high costs of hydrogen, the technically more efficient solution remains the direct electrification and the utilization of domestic renewable resources also in the heat sector, including higher efficiency and use of smaller amounts of energy like waste heat and others.

## 3.2 Global Green Hydrogen Demand

The demand for hydrogen on a global level is even more difficult to estimate than the German one, especially in the long term. The range of scenario results for the future share of hydrogen in the global energy consumption vary significantly Pflugmann and Blasio (2020) have compiled several studies to show the range of study results regarding the future demand for hydrogen on a global scale. The results are presented in Table 2. The range is from 2,500 TWh to 21,000 TWh per year – this would correspond to about 6 to 50 times the expected demand

[28] IEA defines 'low-carbon hydrogen' as "hydrogen produced from renewable and nuclear electricity, biomass, and fossil fuels with CCUS". CCUS, in turn, "includes CCU [carbon capture and use] as well as CCS, including carbon dioxide that is both used and stored (e.g. for enhanced oil recovery or building materials) if some or all of the carbon dioxide is permanently stored." (IEA, 2021b; p. 15).

according to Prognos et al. (2021) for Germany for the year 2045 (see chapter 3.1). None of the scenarios focuses on green hydrogen.

Table 2: Estimated annual demand for hydrogen in 2050

| | Study | Estimated annual demand in TWh | Remarks |
|---|---|---|---|
| **Hydrogen demand in 2050** | Hydrogen Council (2017) | 21,667 | Driven mainly by transportation (6,111 TWh) and industrial energy (4,444 TWh) |
| | BNEF (2019) | 1,389-10,833 | Estimates reflect conservative and optimistic scenarios |
| | DNV (2018) | 4,167-10,833 | Industrial feedstock accounts for more than 40 % of demand in all scenarios |
| | Shell (2018) | 2,500 | Market only grows considerably after 2050 reaching 19,167 TWh in 2100 (mainly driven by road transport, as well as heavy and light industry) |

Notes: values in the table have been converted from EJ to TWh.
Source: Own illustration, based on Pflugmann and Blasio (2020, p. 18).

Only a handful of states and regions produce and consume (green) hydrogen and its derivatives in significant amounts or aim to export (green) hydrogen at all (IRENA, 2022b, 2022a). As of now, China is the largest consumer of hydrogen (of all colors) (close to 9 Mt hydrogen/a), followed by the United States (more than 7 Mt hydrogen/a) and the Middle East (close to 4 Mt hydrogen/a). These three countries/regions alone account for more than half of global demand (IEA, 2021b).

The US accounts for 13 % of global demand for hydrogen,[29] and is slowly stepping up ambitions with its recently announced first 'Energy Earthshot', aiming to reduce the cost of 'clean' hydrogen[30] by 80 % to 1 USD/kg in one decade (Office of Energy Efficiency & Renewable Energy, 2021). Around 80 % of US hydrogen production is based on natural gas reforming (IEA, 2021b).

[29] This is mostly due to its large refining and chemical sectors.
[30] Defined as hydrogen based on renewables, nuclear, or thermal conversion (Office of Energy Efficiency & Renewable Energy, 2021).

IEA indicates that the new installed electrolyser capacity in both the US and China must be considered rather modest.[31] Neither of the two countries aim to export large amounts of hydrogen in the future, but add capacity mainly with the intent to cover the growing demand for so-called 'low-carbon' hydrogen and hydrogen-based fuels domestically (IEA, 2021b).[32]

As of 2019, some of the lowest hydrogen production costs occurred in the Middle East, Russia, and North America (USA and Canada), due to historically low gas prices at the time and the process based on steam reforming. Again, low gas prices do not automatically translate into higher hydrogen exports (IEA, 2021b).

It should be stressed that all figures and scenarios regarding the future global demand for hydrogen are highly speculative. However, they do indicate the rough direction in which the market for hydrogen will develop in the coming years. This is also plausible because the demand growth described for Germany will be paralleled in other industrialized countries. In addition, developing or industrializing countries should ideally not first enter the fossil path and build up corresponding structures, but rather cover their energy needs in the industrial sector with green hydrogen.

# 4 Current and Future Supply of Green Hydrogen

In 2021, green hydrogen still accounted for less than 1 % of global hydrogen production (Johann, 2022). This looks like a very low figure, but in fact in 2019, less than 0.1 % of the world's hydrogen production came from water electrolysis – i.e. was potentially green (IEA, 2019). This suggests a rapid uptake of both green hydrogen and water electrolysis. Most recently, IRENA's 1.5 C scenario envisaged that 'clean hydrogen'[33] could meet up to 12 % of global final energy consumption by 2050 (IRENA, 2022a).

## 4.1 Supply options and trends on a global level

Many countries potentially have access to the input factors necessary for green hydrogen production (electrolysers, water, green electricity, and transport infrastructure), which means that many more countries have the potential to play a supplier role. Many studies assess production as well as import and export potential of countries along different category

[31] This is even though the Chinese energy giant Sinopec began construction on the world's largest green hydrogen production plant in December 2021: a facility with 260 MW of electrolyser capacity expected to enter service by mid-2023, at a projected cost of USD 470 million, with half the needed electricity to run from a 300 MW solar facility and the rest from nearby wind farms, including a hydrogen transportation pipeline with takeaway capacity of 2.5 t per hour (Conrad, 2021). It remains unclear in the IEA report under which category Russia has been included.

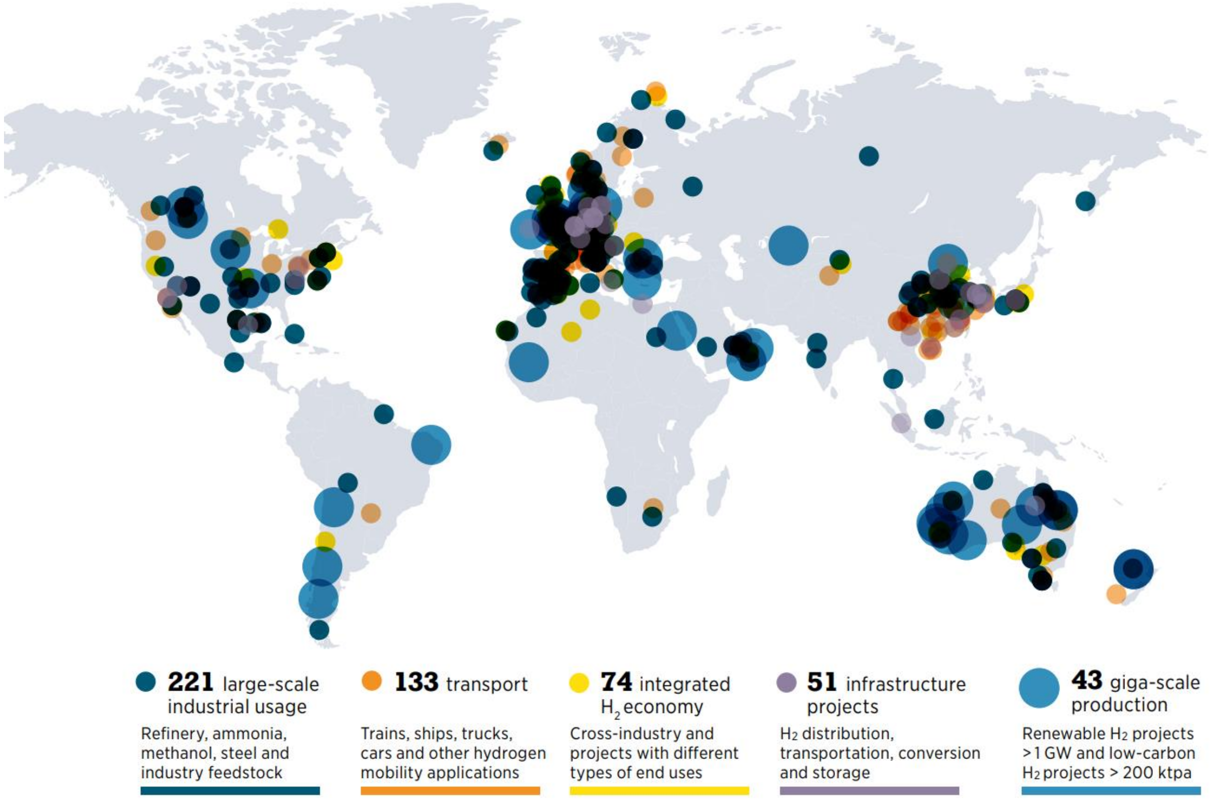
[32] The latter holds especially true for China.

[33] 'Clean hydrogen' refers to a mix of 'green' and 'blue' hydrogen. IRENA's scenario assumes a mix of 2/3 green hydrogen, with gas and carbon capture, use and storage (CCUS) making up 1/3 of the mix.

systems (e.g., Jensterle et al., 2019; Pflugmann & Blasio, 2020) and name particularly suitable candidates for producer countries. In particular, countries with large renewable energy and infrastructure potential are considered future ‘export champions’, including Australia, the United States, Morocco and Norway (Pflugmann & Blasio, 2020).

From a technological and research perspective, the industrialized countries are currently the pioneers in the hydrogen sector, as expected. Figure 3 shows that clean hydrogen projects are rather concentrated in the Global North (including Australia) and East Asia (China and Japan). It is foreseeable that technological pioneers will establish themselves here.

Figure 3: Clean hydrogen projects and investment as of November 2021




Notes: The figure describes large-scale projects only, including commissioning after 2030. It does not include more than 1,000 small-scale projects and project proposals. ktpa = kilotons per annum.
Source: IRENA (2022a, p. 43).

For the moment, however, a large production gap remains globally. IRENA (2022a) stated that the pipeline of announced electrolyser projects globally reached over 260 GW by October 2021, and, if implemented, would bring an additional 475 GW of wind and solar PV capacity online by 2030. “Although this is a dramatic increase from the 0.3 GW of electrolysis that was installed in 2020, it is far from the 160 GW that must be installed on average every year through 2050 to meet the 1.5°C goal.” (IRENA, 2022a) Therefore, the question must be raised as to where the required green hydrogen will come from and which countries or regions can provide the corresponding supply.

Particularly because of the large quantities of hydrogen required by 2050 (see chapter 3.1 and 3.2), very large quantities of renewable energies must be made available for green hydrogen, which in turn generate very large land requirements. It is plausible that, in order to satisfy the global demand for green hydrogen, cooperation between countries with technological leadership and countries with the natural conditions will be developed.

IRENA finds that “green hydrogen could disrupt global trade and bilateral energy relations, reshaping the positioning of states with new hydrogen exporters and users emerging” (IRENA, 2022b). New energy-trading relationships might be the result of some countries aiming to become significant exports of (green) hydrogen (e.g., Australia, Chile, France, Morocco),[34] whilst others prepare to become large-scale importers (e.g., Japan, Korea, Germany) or are heading towards hydrogen self-sufficiency (e.g., the US, China, India, Brazil) (Van de Graaf, 2021).

In this reshaping, and in addition to the potential of renewable energies and the existing infrastructural and industrial base, transport costs play an important role in the locational decisions for production and import/export of hydrogen. From a German or European perspective, it therefore makes sense to cooperate with countries and regions that are geographically close to each other in order to minimize transport costs. Here, the African continent and the Near and Middle East come into focus. Due to lower distances to Europe, these regions have an advantage over countries that will be leaders in the production of hydrogen in the foreseeable future (e.g., USA or Japan) or could have large export capacities (e.g., China or Australia), but have very long distances to Europe and Germany and thus higher transport costs and infrastructural and logistical challenges.

The following chapter therefore examines the extent to which Germany's demand for green hydrogen could be met by African countries or regions.

## 4.2 Hydrogen in Africa and the Global South

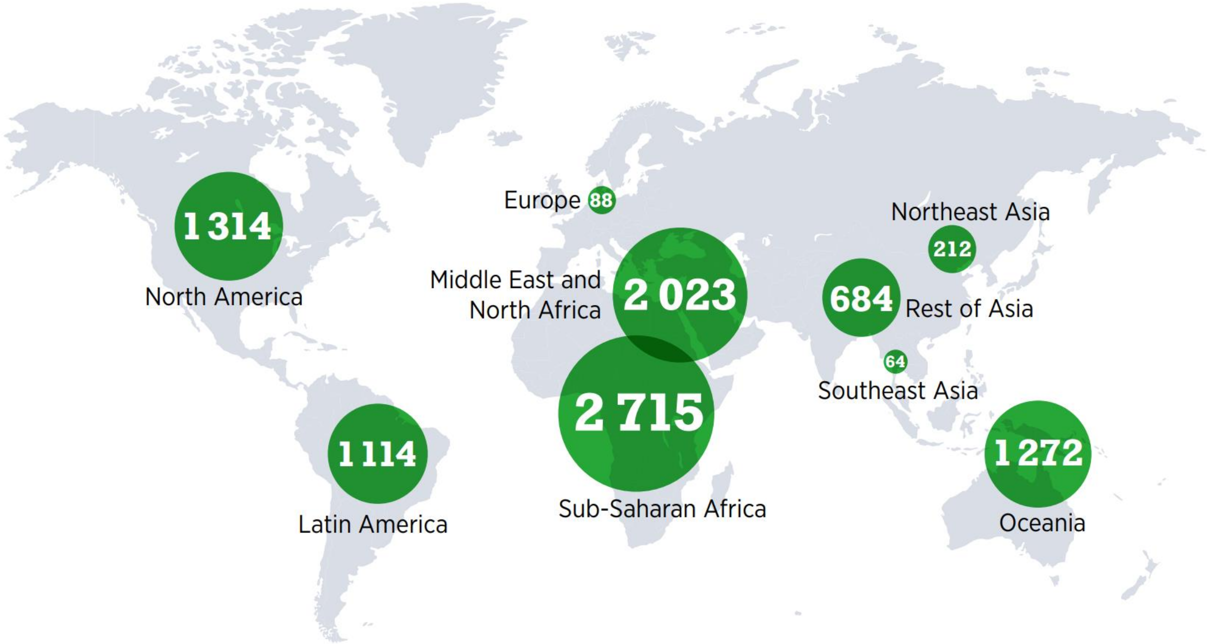
Africa has a comparatively high technical potential to produce green hydrogen (FZ Jülich, 2022) under 1.5 USD/kg by 2050 as Figure 4 illustrates (IRENA, 2022a). The continent is considered by some stakeholders (especially Germany and the EU) a potential production site for imported hydrogen. For example, in formulating its goal of 40 GW by 2030, the EU aimed to import green hydrogen from its “Southern and Eastern Neighbourhood partners and Energy Community countries”, notably Ukraine and member states of the African Union (European Commission [EC], 2020),[35] unfortunately without providing any time

[34] France aims to become a pink “hydrogen powerhouse by 2030” (Lee, 2021). Both Australia and Chile have already announced the aim of producing hydrogen for less than 1.5 USD/kg in the future (Ghosh & Chhabra, 2021)

[35] In the light of the Russian invasion and war in Ukraine that started in February 2022, by the time of writing this study, the EU’s aim seems overhauled. If anything, this might shift the EU’s focus even more to Africa.

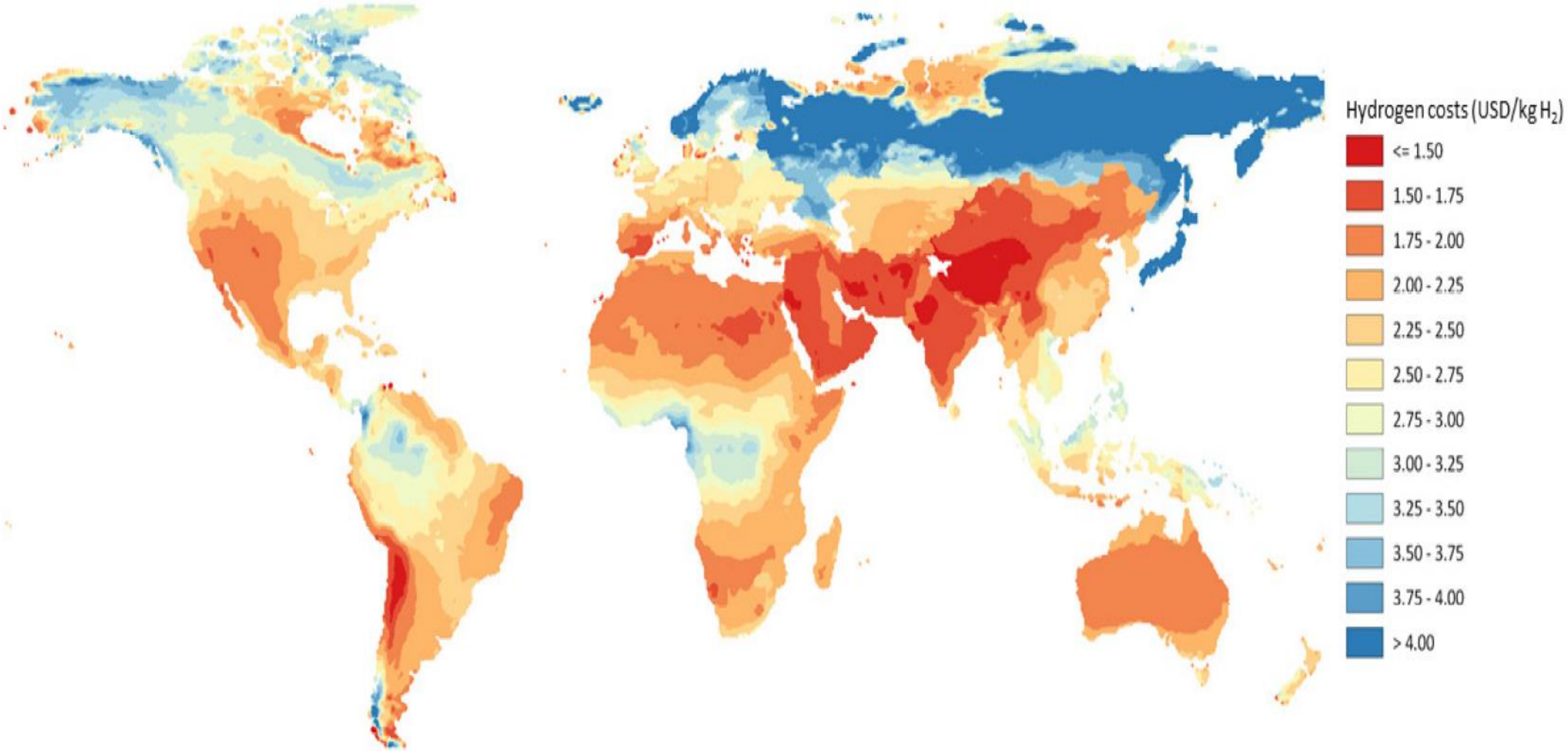
horizons or quantities. Figure 5 illustrates, the low productions costs in Africa, on the Arabian Peninsula and in vast parts of Asia (see the red areas on the map).

Figure 4: Technical potential for producing green hydrogen under 1.5 USD/kg by 2050, in EJ




Source: IRENA (2022a, p. 47).

Figure 5: Hydrogen production cost from hybrid solar PV and wind systems in 2030

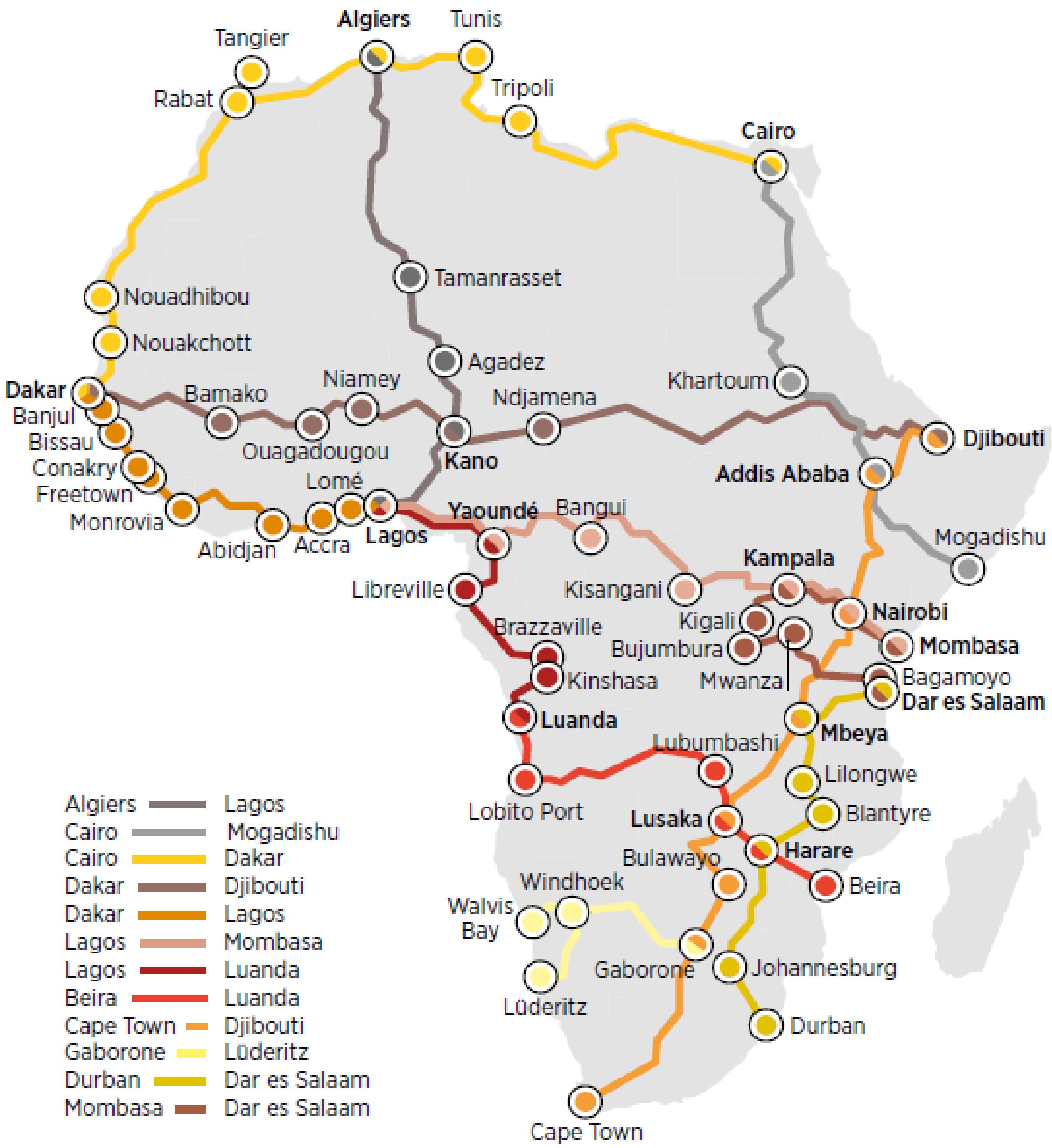



Notes: For each location, production costs were derived by optimizing the mix of solar PV, onshore wind, and electrolyser capacities, resulting in the lowest costs and including the option to curtail electricity generation.
Source: IEA (2021b, p. 126).

For many other world regions, hydrogen imports from West or North Africa will most likely not play a role at all, considering the long transport needed (IEA, 2021b). Figure 6 illustrates how IRENA envisions the necessary (green) hydrogen infrastructure to be set up across the African continent, including the Trans-Saharan Gas Pipeline running from Lagos to Algiers that could be re-functioned to transport (green) hydrogen across the continent.

As of now, high-volume transcontinental hydrogen-only pipelines do not yet exist. A gas pipeline between Africa and Europe, the 4000 km-long Trans-Sahara Gas Pipeline from Nigeria over Algeria to Italy and/or Spain has been discussed for a long time, and could theoretically also transport hydrogen, or exclusively transport hydrogen. With the groundbreaking ceremony for the first subproject, the AKK Gas Pipeline in 2021, a construction period of 25 years is estimated. Completion is not foreseen until well after 2045 (SCI4climate.NRW et al., 2021).

Figure 6: Possible hydrogen routes across Africa along existing and future trans-African highways




Source: IRENA (2022, p. 75).

Hardly any trade routes are currently established or under development for exporting (green) hydrogen from the African continent, with the exception of South Africa, Namibia and Morocco (Figure 7).[36] Many more trade routes especially by ship can be expected in the near and medium-term future, facilitated by, among others, dedicated 'hydrogen offices' (e.g. by Germany in partnering countries) (Auswärtiges Amt, 2021; GIZ, 2021a, 2021b) and the ever-increasing number (41) of Bilateral Hydrogen Partnerships (Bateman, 2021).

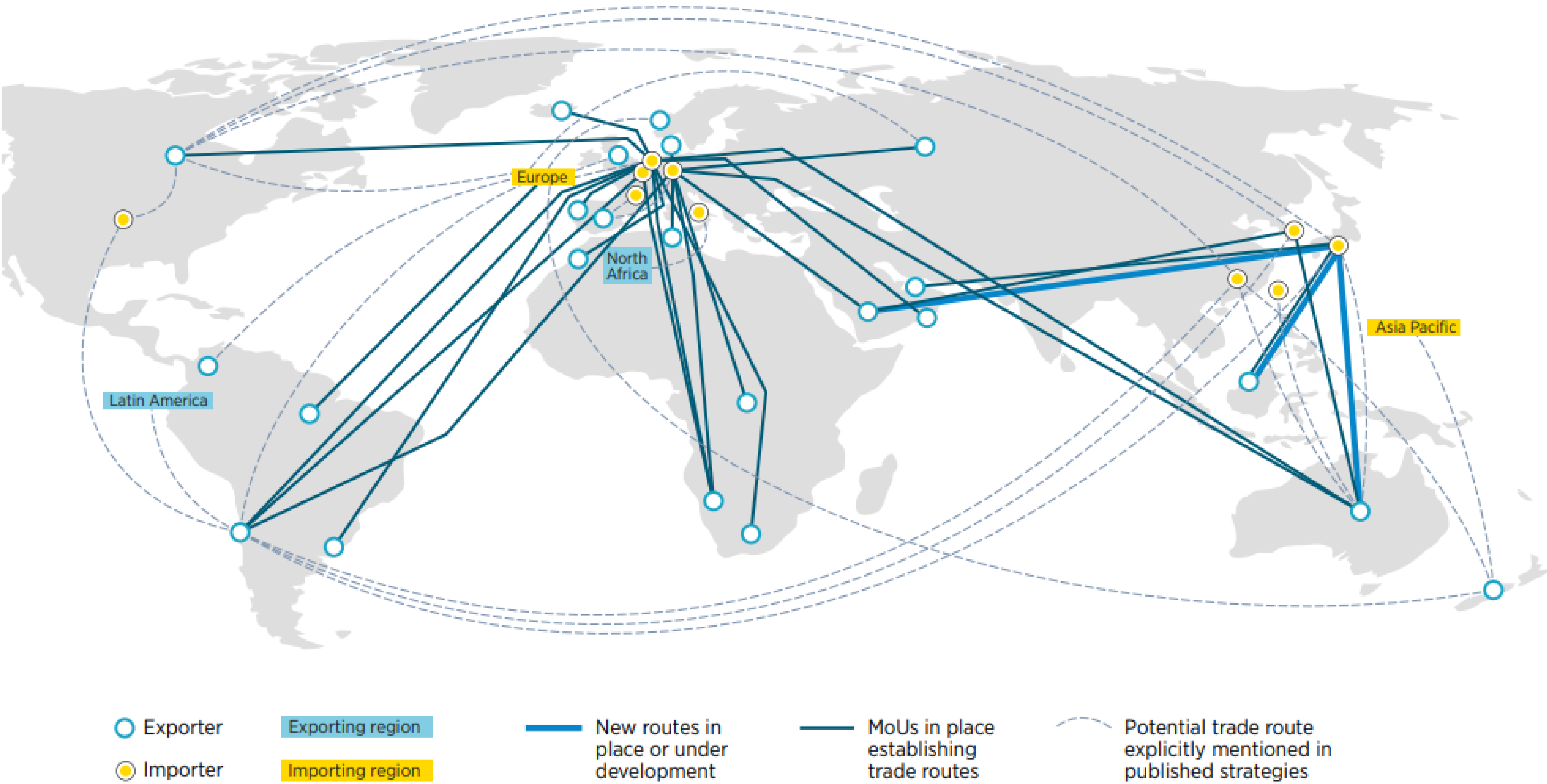
From a political viewpoint, in the most recent EU-Africa summit, leaders from both sides agreed on a joint vision for a renewed partnership, based on the aims of solidarity, security, peace and sustainable and sustained economic development and prosperity for the citizens of both the EU and the African Union (AU). While hydrogen has not been mentioned specifically, the Africa-Europe Investment Package aims to support a common ambition for 2030 and the AU Agenda 2063 with EUR 150 bn by 2030. This includes, among others, three areas with direct linkages to (green) hydrogen: energy, transport and digital infrastructure; energy transitions; and green transition (European Council, 2022).

From a technical viewpoint, as was shown in Figure 4, vast parts of Africa could provide for rather low hydrogen production costs by 2030. As Europe's neighboring continent, transportation costs for hydrogen would be significantly cheaper than, for example, importing hydrogen from Australia, either via pipelines (see Figure 6) or shipping (see Figure 7). With rather low installed capacity of renewable energy sources (see IRENA 2020c) and frequent occurrences of droughts and water scarcity in various regions of the continent, however, the choice among African countries becomes more limited and all of them still have to create the right framework conditions to produce and potentially export (green and fair) hydrogen in the future. High amounts of solar radiation promise lower electricity generation costs as in Europe (FZ Jülich, 2022), as the world's largest solar complex Ouarzazate in Morocco demonstrates.

These and further issues such as the need for freshwater desalination plants and their interconnection with local populations and regions will be discussed in the next chapter for three case studies (Morocco, Niger, Senegal), and possible demands from countries of the Global South to hydrogen importers from the Global North been outlined.

[36] Though the DRC is included in IRENA's map, the authors are not aware of any formalised agreement on hydrogen exports, nor does IRENA itself map any hydrogen projects in the country (IRENA, 2022; p. 43). Another factor complicating the trade of hydrogen is the lacking global harmonisation of hydrogen certification, as the eponymous study by Germany's energy agency comparing eleven different countries recently found (World Energy Council - Germany & German Energy Agency, 2022).

Figure 7: Network of hydrogen trade routes, plans and agreements




Notes: Based on the information contained in government documents as of late 2021. MoUs = Memorandums of Understanding.
Source: IRENA (2022, p. 12).

# 5 Hydrogen policies in Germany and the EU

In the following, Germany's approaches to producing and importing green hydrogen shall be presented and compared briefly with the EU's approach. They will also be analyzed to determine whether sufficient safeguards are integrated to offset or prevent the potential economic, environmental, and social impacts associated with the emerging global hydrogen production.

## 5.1 Germany's hydrogen policy approach

Germany's approach to hydrogen is expressed in the German government's National Hydrogen Strategy. It is in a revision process under the new coalition government. In the export-import context, Germany's Act on Corporate Due Diligence in Supply Chains and the hydrogen criteria of the National Hydrogen Council are also of particular relevance. These are presented below.

### 5.1.1 Germanys National Hydrogen Strategy

The National Hydrogen Strategy (*Nationale Wasserstoffstrategie* – NWS), passed in 2020,[37] aims to start a market ramp-up and harness expansion opportunities for hydrogen production by 2023 (phase 1). By 2030 (phase 2), the market ramp-up shall be strengthened both nationally and internationally and shall provide "the basis for private-sector investment in hydrogen generation that is both economically viable and sustainable, […] in its transport and use" (Bundesregierung, 2020b; p. 3).

[37] The 13 overarching aims of the NWS are: (1) Assuming global responsibility; (2) Making hydrogen a competitive option; (3) Developing a domestic market for hydrogen technology in Germany, paving the way for imports; (4) Establishing hydrogen as an alternative for other energy sources; (5) Making hydrogen a sustainable base material for the industrial sector; (6) Enhancing transport and distribution infrastructure; (7) Fostering science, mobilising skilled labour; (8) Shaping and accompanying transformation processes; (9) Strengthening German industry and securing global market opportunities for German firms; (10) Establishing international markets and cooperation for hydrogen; (11) Regarding global cooperation as an opportunity; (12) Building up and securing the quality assurance infrastructure for hydrogen production, transport, storage and use, and building trust; (13) Improving the policy environment and addressing current developments on an ongoing basis.

**Box 3: Germany's NWS by measures**

In total, 38 measures were agreed on for the NWS to be implemented by federal and regional government representatives in cooperation with (international) partners (Bundesregierung, 2020). They are subsumed under six thematic fields[38] of which 'international hydrogen market and external economic partnerships' is the only one with immediate relevance for the import of green hydrogen. This field's five measures (and various sub-measures) put forward can be summarized as follows:

- 34. Integrate hydrogen into existing energy partnerships and establish new partnerships;
- 35. Foster the cooperation with partner countries in the context of a hydrogen alliance in coordination with EU initiatives;
- 36. Strengthen existing international activities, particularly in the context of the energy partnerships and of multilateral cooperation;
- 37. Pilot projects in partner countries, including as part of German development cooperation involving German firms;
- 38. Intensify the dialogue with current exporters of fossil fuels, with a view to a gradual global energy transition including hydrogen.[39]

The German National Hydrogen Strategy in its measure 37 states t that every import of green hydrogen or its derivatives must take place on top of domestic energy production ('additionality principle'). This criterion is fundamental to addressing some of the most important economic and ecological challenges associated with hydrogen production. Observing it, Germany would have to define strict, truly sustainable criteria for 'fair green hydrogen' at the national level before large(r) quantities of hydrogen are to be imported in the near(er) future.[40]

The new German government coalition of Social Democrats, Greens and Liberals (since 2021) has recently doubled the target of installed hydrogen electrolyser capacity from 5 GW to 10 GW by 2030 (Radowitz, 2021). This update will be embedded in an overhaul of the existing National Hydrogen Strategy which is announced for this year.

[38] These are: hydrogen production; fields of application (transport, industrial sector, heat); infrastructure/supply; research, education, innovation; need for action at European level; international hydrogen market and external economic partnerships.

[39] It deserves note that measure 35 suggests that Germany is not interested in green hydrogen alone, but 'climate-neutral hydrogen' more generally – which could also include nuclear power-generated hydrogen, among others. The NWS contradicts itself to some extent by stating in a footnote that "[t]he Federal Government considers only hydrogen that has been produced using renewable energy (green hydrogen) to be sustainable in the long term." (Bundesregierung, 2020b; p. 2).

[40] It is particularly stunning that one sub-measure of Measure 34 and Measure 36 are more or less identical, and that at no point 'short term' or 'long term' are defined in the document.

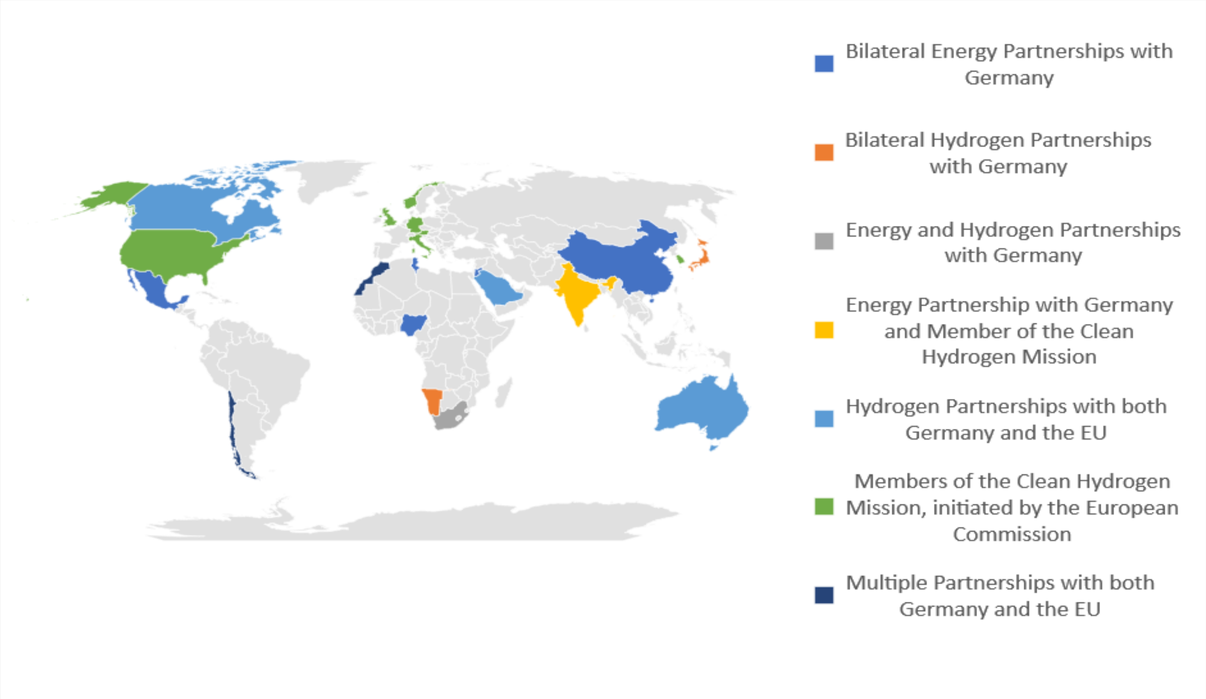
### 5.1.2 Hydrogen Partnerships and other measures

One important instrument for Germany's foreign trade policy are bilateral partnerships in the energy sector (NWS measure 34 and 36). Bilateral Energy Partnerships are intended to "bring together high-level intergovernmental dialogue with practical, goal-oriented project work" (GIZ, 2021a), across energy-related areas and on country-specific priorities. Germany maintains a number of such energy partnerships as well as some partnerships that are specifically focused on hydrogen (Dietz-Polte & Vacha, 2021; GIZ, 2021a). These partnerships exist with countries in both the Global North and the Global South (see Figure 8).[41]

So far, Germany has entered into eight officially communicated Bilateral Hydrogen Partnerships with governments of other countries, as of March 2022 (Table 3). Three of them build on existing Bilateral Energy Partnerships (Chile, Morocco, South Africa). Implementing measure 35 of the NWS, Germany is also a member of the Clean Hydrogen Mission initiated by the European Commission (EC), on top of its Bilateral Hydrogen Partnerships and Bilateral Energy Partnerships. Some of the partner countries under the Clean Hydrogen Mission are also bilateral partners of Germany, as Figure 8 illustrates.

[41] Overall, though, Bilateral Hydrogen Partnerships tend to be more common between countries of the Global North (Ghosh & Chhabra, 2021).

Figure 8: International energy and hydrogen partnerships by Germany and the EU




Notes: The Hydrogen (H2)-Atlas Africa (FZ Jülich, 2022) for 31 West and Southern African states has not been considered as it does not represent a partnership in its own right. Nigeria has been added even though it is not a member state of the Bilateral Energy Partnerships, but since the Nigerian Energy Support Programme II by GIZ has been built upon in November 2021 with the opening of a German Hydrogen Office in Abuja (Auswärtiges Amt, 2021; GIZ, 2021a, 2021b).[42]

Source: Own illustration, based on Dietz-Polte and Vacha (2021) and GIZ (2021a).

All of Germany's current Bilateral Hydrogen Partnerships are listed in Table 3. In quantitative terms, only the size of the demonstration plant in Morocco (measure 37) has been announced at this point, with a capacity of 100 MW. Against this background, it must be noted that at least for the 2030 time period, no contractually binding import agreements exist at this point, which would satisfy the hydrogen needs calculated above.

[42] The German Federal Foreign Office is currently also setting up dedicated hydrogen diplomacy offices linked to its embassies in Luanda (Angola), Moscow (Russia), Riyadh (Saudi Arabia) and Kiev (Ukraine) (IRENA, 2022a). As of mid-February 2022, three more bilateral energy partnerships have been planned with Germany: Egypt, Senegal and Côte d'Ivoire (Ehlerding, 2022). If this map was to be expanded, it would also show that Bilateral Hydrogen Partnerships tend to be more common between countries of the Global North (Ghosh & Chhabra, 2021).

Table 3: Elements of Germany's Bilateral Hydrogen Partnerships with international partners

| Country | Existing Bilateral Energy Partnership* | Agreement | Elements |
|---|---|---|---|
| **Australia** | | Germany Australia Hydrogen Accord (2021) | • German-Australian joint Hydrogen Innovation and Technology Incubator (HyGate) for applied research and pilot projects along the entire hydrogen supply chain<br>• Demonstration projects<br>• Hydrogen trade cooperation<br>• USD 92 million committed to fund hydrogen projects (Germany: USD 56 million [EUR 50 million]; Australia: USD 36 million) via HyGate, with first bids expected in the first quarter of 2022** |
| **Canada** | Since 2021 | Memorandum of Understanding (2021) | • Energy partnership with major component on hydrogen<br>• Collaborate on clean hydrogen, its derivatives and potential applications, and identify potential cooperation projects on the production, usage and trade of clean hydrogen |
| **Chile** | Since 2019 | Memorandum of Understanding (2021) | Establishment of a Hydrogen Task Force within the existing German-Chilean Energy Partnership:<br>• Intensify cooperation<br>• Identify opportunities for the creation of consortiums and for investments<br>• Create suitable framework conditions for the development of a hydrogen economy<br>• Identify concrete joint pilot and demonstration projects |
| **Japan** | | Framework announcement (2021) | • Promote research cooperation<br>• Establish sustainable international knowledge and innovation networks<br>• Create a lasting research, development, and innovation partnership<br>• Up to EUR 600,000 per collaborative project for the German side, up to 36 months |

| | | | |
|---|---|---|---|
| **Morocco** | Since 2012 | Memorandum of Understanding (2020) | • Joint development of green hydrogen production technologies<br>• Construction of a hydrogen plant (100 MW capacity) to supply Germany, with EUR 300 million already been pledged by the German Development Bank (KfW)***<br>• Expansion of infrastructure in Tangier and Hamburg to export/import hydrogen via tank ships |
| **Namibia*** | | Joint Communiqué of Intent (2021) | • Up to EUR 40 million in funding from the economic stimulus and future package for cooperation |
| **Saudi Arabia** | | Memorandum of Understanding (2021) | • Bilateral innovation fund to promote clean hydrogen<br>• Planned use of German technologies and involvement of German companies in implementing clean hydrogen projects<br>• Intended export of clean hydrogen and downstream products |
| **South Africa** | Since 2013 | Memorandum of Understanding (2021) | • KfW-program to support development of green hydrogen projects (EUR 200 million)<br>• Power-to-X (PtX) Pathway Project by BMUV: Support to development of sustainable hydrogen/PtX markets in South Africa and other countries |

Source: Own illustration, based on Dietz-Polte and Vacha (2021); * = GIZ (2021a), ** = Reuters (2021), *** = Ghorfa (2021).

Besides these bi- and multilateral partnerships on state level, there are various other measures of relevance.[43] Several financial support mechanisms exist and will be discussed in a later chapter. Informational tools are provided, as well. One such tool is the Hydrogen ($H_2$)-Atlas Africa, which is an interactive map commissioned by Germany's Federal Ministry of Education and Research showing and quantifying West Africa's vast potential for hydrogen production in detail: Its expansion to other African regions is planned.

Various other forms of hydrogen cooperation have already been initiated between Germany and countries in the Global South (beyond development cooperation – NWS measure 37), including for example the establishment of a West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) with its graduate school programme to train the hydrogen professionals of tomorrow (BMBF, 2021; FONA, 2021).

### 5.1.3 Germany's Act on Corporate Due Diligence in Supply Chains ('*Lieferkettensorgfaltspflichtengesetz*')

Germany's Act on Corporate Due Diligence in Supply Chains ('*Lieferkettensorgfaltspflichtengesetz*' [LkSG]) is intended to improve the international human rights situation by defining responsibilities for the management of supply chains.[44] Applicable from 1st January 2023 for companies headquartered in Germany and companies with a branch in Germany (*Bundesministerium für Wirtschaft und Klimaschutz* [BMWK], 2022),[45] companies have to ensure that they fulfil the a number of due diligence obligations against human rights violations (BMWK, 2022):

- Establishment of a risk management system,
- Designation of an internal responsibility,
- Carrying out regular risk analyses,
- Establishing preventive measures in the own business unit, towards direct suppliers and – if there are indications of possible violations – towards indirect suppliers,
- Taking corrective action,
- Establishment of a complaints procedure and
- Documentation and reporting.

Human rights violations can include environmental and social aspects. But the law needs to be further tested in practical operations. Considering that the LkSG has not yet entered into force, it remains unclear as to whether it can ultimately help preventing or reproducing structures and practices that would be harmful to African partner countries. In any case,

[43] Other forms of cooperation are not included in Figure 8 for the sake of comparability.
[44] As of 2020, only 22 % of German businesses voluntarily monitored their foreign subsidiaries and contractors for human rights compliance (European Parliament, 2020).
[45] From 1st January 2023 for companies with at least 3,000 employees; from 1 January 2024, companies with at least 1,000 employees in Germany (BMWK, 2022b).

however, LkSG will make it more difficult for there to be inhumane working conditions and exploitation as the epitome of (neo-)colonial structures within the supply chain of large German companies. Thinking in terms of value chains, this would also include precious metals as those needed for electrolysers producing hydrogen (Johann, 2022).

It deserves notice that it can be expected that the European Parliament will draw heavily on Germany’s LkSG in its strive for a mandatory EU system of due diligence for supply chains (European Parliament, 2020).[46] At the same time as the extension and deepening of such standards across governance levels is promising for ensuring human rights, it must not be forgotten that no international standards for producing hydrogen in a fair manner exist at this point.[47]

## 5.2 The EU’s approach

The German approaches, especially the NWS and Germany’ s Act on Corporate Due Diligence in Supply Chains, interact closely with the European level activities. This is also of particular relevance in the context of trade and energy issues, which is why the European approach to (green) hydrogen will be briefly presented and discussed below.

Similar to, and to some extent aligned with Germany, the European Commission also works on ‘hydrogen diplomacy’. Illustrated in Figure 8 above, the Clean Hydrogen Mission and Hydrogen Partnerships with the EU are supposed to contribute to the EU’s ‘phased approach’ for upscaling hydrogen installation and deployment. The EU’s ‘Hydrogen strategy for a climate-neutral Europe' follows a similar phased logic as Germany’s approach, as outlined by Matthes et al. (2021): To build a foundation for a rapid scale-up of own green hydrogen infrastructure by the mid-2020s and scale up in the following two to three decades.

[46] Non-governmental organisations (NGOs) and other political actors will most likely be possible plaintiffs in the case of the EU of due diligence for supply chains as well since every EU country has to implement EU directives into national law.

[47] The authors are away of the argument that, thus, the threat of free riding of countries outside the EU might increase. Further research should enquire this ‘downward spiral’ vs. ‘upward spiral’-discussion specifically for the case of hydrogen. At the European level, there are currently also efforts to introduce a European supply chain law that sets new standards that could go beyond the German standards (EC, 2022).

Table 4: The EU's phased approach for scaling up green hydrogen[48]

| 2020-2024 | 2025-2030 | 2030-2050 |
|---|---|---|
| Support the installation of at least 6 GW of renewable hydrogen electrolysers in the EU, in order to produce up to 1Mt of renewable hydrogen. | Installation of at least 40 GW of renewable hydrogen electrolysers and the production of up to 10 Mt of renewable hydrogen in the EU. | Reach maturity for renewable hydrogen technologies and be deployed at large scale across all hard-to-decarbonize sectors such as chemicals and steelmaking. |

Source: Own illustration, based on EC (2020) and Simon (2020).

In direct comparison it becomes clear that, so far, the German and the EU's respective hydrogen strategies use differing time frames (Table 5). Both strategies were agreed on in 2020, but they hardly inform each other. Thus, it is on Germany's new government to better align the two in its promised new National Hydrogen Strategy. So far, however, both strategies already include some large-scale projects on green hydrogen – research projects in the case of Germany, but green hydrogen infrastructure projects in the case of the EU strategy.

[48] In the light of the Russian invasion of and war against the Ukraine since late February 2022, the EU has already communicated its intention to update is hydrogen strategy in order to reduce its fossil fuel-dependency on Russia as soon as possible (Lohse, 2022).

Table 5: Germany's and the EU's hydrogen strategies

| Criteria | Germany | EU |
|---|---|---|
| **Production/capacity target by 2030** | 14 TWh of green hydrogen production with 20 TWh of renewables by 2030-35 (5 GW electrolyser capacity) | 6 GW of electrolyser capacity by 2024 and 40 GW by 2030 |
| **Meeting projected industrial demand[49] with green hydrogen production aims** | More than 80 TWh of green hydrogen demand from steel production by 2050 and an additional demand of 22 TWh from German refinery and ammonia production | Production targets of 1 million and 10 Mt of renewable hydrogen per year for 2024 and 2030 respectively, with 50 % renewable hydrogen consumption in industry by 2030 |
| **Promised funding for and projected investments in green hydrogen infrastructure in this decade** | The COVID-economic recovery package provides USD 11.4 bn towards hydrogen (out of a total of USD 165 bn); funding worth USD 1.7 bn will be provided within the Hydrogen National Strategy up to 2026 | Investments in renewable hydrogen worth USD 280-430 bn for electricity production and USD 30.5-53 bn for electrolysers by 2030 |
| **Large-scale projects under development/planning** | Three large-scale projects on green hydrogen – $H_2$Giga, $H_2$Mare and TransportHyDE, supported with EUR 700 min total, running until 2025 | Eight projects developed with the IPCEI (Important Projects of Common European Interest) framework covering 17 EU member states and requiring 43 GW of renewable energy deployment for green hydrogen production |

Source: Bundesregierung (2020b), EC (2020), Ghosh and Chhabra (2021); IEA (2021a).

[49] Demands of other sectors for which the application of hydrogen is of relevance are not quantified in either of the two strategies. The EU, for example, shows an understanding of 'industrial demand' and that of other sectors very similar to that of Germany, ensuring that its second phase (2025-2030) will "gradually include new applications, including steel-making, trucks, rail and some maritime transport applications, and other transport modes […]" and that "a dedicated hydrogen infrastructure can use hydrogen not only for industrial and transport applications, and electricity balancing, but also for the provision of heat for residential and commercial buildings." (EC, 2020; p. 6).

The EU lags behind its own plans with regard to the production and import of green hydrogen.[50] And even if the EU were to meet its targets, this would not be enough to cover Germany's import demand for green hydrogen. The gap between demand and Germany's and the EU's own production capacities, which is widening over time, should therefore be covered by imports from outside Europe.

### 5.2.1 Criteria for Green Hydrogen in the EU

Criteria for green hydrogen at the EU level are also being established (Oyarzabal et al., 2022). As of late February 2022, the EU Commission is preparing to launch an EU-wide database to certify the carbon footprint of hydrogen – of which 96 % are currently reliant on fossil fuels – and other so-called ‘low-carbon’ fuels in a harmonized way (Kurmayer, 2021). By 2050, the EU expects almost ¼ of global energy demand to be met by green hydrogen, thus playing a key role in its own climate goals (EC, 2020). By then, with annual global sales of up to EUR 630 bn, this would translate into 1 million jobs in the hydrogen value chain in Europe alone (Simon, 2020).

An important step towards the implementation of the EU Hydrogen Strategy was the legislative package on hydrogen and decarbonized markets in December 2021 (EC, 2021b), which - as of March 2022 - is still under consideration. The Commission's legislative package aims to promote the use of blue hydrogen until at least 2030, provided it achieves at least the same level of decarbonization as green hydrogen (i.e., 70 % greenhouse gas reduction).[51] The legislative package also proposes new rules for the development of a hydrogen market in the EU. These bring legal clarity to the definition and role of green and low-carbon hydrogen within the EU. For example, the proposed Gas and Hydrogen Directive defines renewable hydrogen as hydrogen that (i) derives its energy content from renewable sources other than biomass and (ii) achieves a 70 % reduction in greenhouse gas emissions compared to fossil fuels. Low-carbon hydrogen is defined as hydrogen whose energy content comes from non-renewable sources and which achieves a GHG emission reduction threshold of 70 % compared to hydrogen from fossil fuels (EC, 2021) – this thus includes blue hydrogen (Oyarzabal et al., 2022).

One important step to implement the EU’s Hydrogen Strategy has been the proposal for a directive amending Directive (EU) 2018/2001 for the promotion of energy from renewable sources in April 2021 (EC, 2021). Even though the EU still has not defined ‘green hydrogen’,

[50] This is exacerbated by the EU’s promotion of ‘low-carbon’ hydrogen. Various campaigning groups have criticised using such hydrogen (with CCS) in the transition period would “a gift to fossil fuel companies.” (Simon, 2020).

[51] The European Parliament and the Council can still change both the proposed definition and the conditions for blue hydrogen as well as the proposed regulatory incentives through the following legislative procedure.

this regulation can be considered to set the remarkable standard for the sustainable production of hydrogen (Oyarzabal & Falco, 2021).

In addition, the Delegated Regulation (EU) 2021/2139 formulates criteria for sustainable hydrogen activities o assess whether the listed economic activities may qualify as contributing substantially to climate change mitigation and adaptation. With respect to hydrogen, the Delegated Regulation establishes mitigation and adaptation criteria (EC, 2021a; Oyarzabal & Falco, 2021).

Compared to the recommendations made by Germany's hydrogen strategy, however, the EU's sustainability criteria for manufacturing (green) hydrogen largely ignore potential consequences of an unrestricted development of hydrogen production, merely stating that the manufacturing of hydrogen should not adversely affect other adaptation efforts. It is against this de facto-minimum criteria that the key actions of the EU's Hydrogen Strategy must be understood. Among others, it aims to import green hydrogen from its "Southern and Eastern Neighborhood partners and Energy Community countries", notably Ukraine and from member states of the African Union in the framework of the Africa-Europe Green Energy Initiative – without providing any time horizons or quantities (EC, 2020). Crucially, the EU is about to finalize the delegated act for "renewable liquid and gaseous transport fuels of non-biological origin" in 2022 which will help decide the future of the fledgling European hydrogen industry itself (van Renssen, 2021).

It is anticipated that a supply chain law will also be passed at the European level. Non-governmental organizations (NGOs) and other political actors will most likely be plaintiffs for supply chain due diligence at the EU level as well, since each EU country must transpose the EU directives into national law.

## 5.3 Foreseeable consequences of an unrestrained hydrogen economy

Based on the identified demand for green hydrogen for Germany and Europe, the political hydrogen strategies, the German and European gap between demand and own supply capacities, the potential for green hydrogen in Africa and the geographical proximity of the European and African continents, it cannot be excluded that the African continent will be a target for hydrogen production projects carried out by actors of the Global North in the future. This bears significant risks for the countries. On the other hand, if done right, it can offer a significant development opportunity for countries in the Global South and specifically in Africa, satisfying local needs, providing jobs and continuous income from a participation in energy markets as a supplier.

But large investment projects in the Global South, specifically with an export-orientation to provide basic commodities for the Global North, reminisce of exploitative economic relationships and practices of the colonial times and the oil era. Such developments need to be avoided.

hydrogen specifically, upscaling production could perpetuate or create new practices of 'economic colonialism', though under the guise of being 'green'. For example, Scita et al. (2020, p. 30 f.) stress that "the hydrogen revolution […] carries a risk of green colonialism, i.e. the risk of considering developing countries solely as the providers of raw material […]."[52]

Similar to the case of the European Green New Deal, postcolonial critiques of hydrogen could be that most discussions around it "ignore both the global nature of the climate crisis and the colonial history from which it has fundamentally emerged" (Knox, 2021). But in fact, the dynamics are more subtle. Dreaming of large-scale import of (green) hydrogen mostly from countries of the Global South to the Global North ultimately perpetuates a pattern in which the survival and security of those living within Western borders are put above the needs of those living outside of it, for example, in cases where the development of hydrogen production capacities comes at the expense of national efforts to achieve the respective climate neutrality targets, economic development or electrification of the country.

Among others, van de Graaf stresses that the 'Hydrogen Hype' is the product of the expectation that hydrogen could "become the next great prize, a zero-carbon version of oil" (Van de Graaf, 2021; p. 30). The current hydrogen hype could be the start of a new gold rush.

But so far, the bulk of hydrogen programs – and the associated economic opportunity – is concentrated in countries of the Global North and a large part of the bilateral partnerships are between countries of the Global North (Ghosh & Chhabra, 2021).[53] Establishing infrastructure for hydrogen transport seems simpler and less costly along established trade routes – in other words, the winners of globalization are also in the pole position to become the winners of the 'Hydrogen Economy', irrespective of their location factors (water, solar power, investment capital) – at least in the short to medium-term. In that sense, in line with the definition of Adoko et al. (2021, p. 196),[54] neo-colonial structures in hydrogen can arise in the neglect to include Africa and other continents into the economic and development opportunities that arise from the new technology, particularly if the decision makers here or there feel that they need to make unsustainable compromises to make up for other disadvantages (like a less preferable position along a trade route).

In fact, countries of the Global South are currently not integrated into the emerging global hydrogen infrastructure on an equal footing and in a meaningful way, and there is a risk that

[52] No working definition of 'neo-colonialism' will be given here. See for example the definition by Adoko et al. (2021, p. 196). See for other ongoing practices of 'green' neo-colonialism for example (Knox, 2021).

[53] More precisely, of the 33 countries and regions analysed by (Ghosh & Chhabra, 2021), only seven are located in Asia, two of which are countries of the Global North (three are major oil and gas producers). Only Morocco and South Africa are featured on the African continent, even though many other regions could claim to be good sites for green hydrogen, e.g., West Africa.

[54] According to which "[n]eo-colonialism presupposes a practice where former colonizers and or new emerging super-powers subtly impose their interests and enforce economic, political, and cultural dominance over other nations. It is a modern manifestation of colonialism that occurs when colonial powers subtly control power, the political and economic institutions of former colonies with the intention of creating perpetual dependency […]."

they will be excluded from the global energy structures and the high investment requirements might contribute to this persisting for a long time. Due to the high infrastructural and energy-intensive requirements for the production of hydrogen, it is to be expected that once production clusters have been established, they will remain in place due to path dependencies. If countries of the Global South do not turn to this emergent field and build up capacities and structures, it is not unlikely that they can be left behind or dependent on countries of the Global North for importing hydrogen in the medium and long term even if they could produce it locally.

Therefore, it can be seen as relevant that countries of the Global South build up hydrogen production capacities both for their own needs and for export, and thus overcome their current dependence on fossil fuels and corresponding structures.[55] On the other hand, trade relations always have the risk of mutual dependency and it could be argued that a too forceful expansion of hydrogen investments for the sake of any individual customer could be leading to similarly unbalanced economic situations as earlier colonial structures. It should also be noted that this would argue for a very market-oriented dynamic in the scale up and it is not easy to imagine that this could be a process of high inclusivity.

# 6 Case studies

West Africa alone has the technical potential to generate 1,500 times Germany's expected green hydrogen need of 2030 (BMBF, 2021). From a European viewpoint, Africa's proximity promises lower transportation costs than other parts of the world's, especially given the fact that several means of transportation (pipelines or ships) on and from the African continent are considered feasible (see Figure 6 and Figure 7).

In order to discuss both, the possibility of producing and exporting 'fair green hydrogen' as well as the challenges for a quick scale-up of the production of green hydrogen on African continent, three countries have been chosen for a case study discussion: Morocco, Niger and Senegal. The latter two are West African countries that have been covered by the $H_2$-Atlas Africa as of spring 2022 and thus there is a good foundation for a discussion of their generation potential. As of yet, none of them are having hydrogen partnerships with Germany or the EU (see Table 3 and Figure 8). Morocco, on the other hand, is already part of several partnerships with both Germany and the EU (see Table 3 and Figure 8).

The case studies were also selected along their prototypical characteristics. Niger is a good example of a landlocked country and arid natural conditions, typical for a number of African states. Landlocked countries (like Niger) face different challenges than coastal states

[55] Chile is only one example for a country located in the Global South that published its own National Green Hydrogen Strategy, with the aim to turn Chile into a frontrunner in the green hydrogen generation and exportation market (Hilger, 2021; Gobierno de Chile, 2021), with support of e.g. the existing German-Chilean Energy Partnership (Dietz-Polte & Vacha, 2021).

(like Morocco or Senegal) in terms of logistics and transport of resources such as hydrogen. Landlocked countries need to bridge large distances on land, which is why technical solutions such as pipelines might play a greater role here. In large countries such as Niger or Morocco, the questions of space and land use plays a rather subordinate role, as the population and settlement density is overall lower and often concentrated in specific parts of the country. On the other hand, the geographic distances to be overcome between locations in these countries are greater, which can pose not only logistical but also security challenges. Senegal, as a coastal state, is prototypical for another set of African states. Thus, together the three case studies exemplary illustrate the chances and risks for the African continent with regard to producing and exporting green hydrogen in the near- to long-term future.

The presentation and discussion of each of the three case studies will be structured as follows: First, a geographic and energy-related overview of the country will be given and discussed, followed by energy-related problems, thus embedding the respective potential of and barriers to producing green hydrogen. Every case study will be briefly summarized in a SWOT analysis: Strengths in this analysis are to be interpreted as positive locational factors for producing hydrogen for export, weaknesses as negative locational factors. Opportunities are specifically formulated with respect to the opportunities for (positive) movements towards the SDGs, while threats include risks of perpetuated if not increasing dependency on (hydrogen-)importing countries.

Table 6: Comparison of selected socio-economic data of the three cases.

| Socio-economic data | Morocco | Niger | Senegal |
|---|---|---|---|
| **Population size (as of July 2021)** | 36,561,813* | 23,605,767 | 16,082,442 |
| **Area** | Total: 716,550 $km^2$<br>Land: 716,300 $km^2$<br>Water: 250 $km^2$ | Total: 1,267,000 $km^2$<br>Land: 1,266,700 $km^2$<br>Water: 300 $km^2$ | Total: 196,722 $km^2$<br>Land: 192,530 $km^2$<br>Water: 4,192 $km^2$ |
| **Real GDP per capita (as of 2020)**[56] | USD 6,900 | USD 1,200 | USD 3,300 |
| **Government type** | Parliamentary constitutional monarchy | Semi-presidential republic | Presidential republic |
| **Median age (as of 2020)** | Total: 29.1 years<br>Male: 28.7 years<br>Female: 29.6 years | Total: 14.8 years<br>Male: 14.5 years<br>Female: 15.1 years | Total: 19.4 years<br>Male: 18.5 years<br>Female: 20.3 years |
| **Urban population (as of 2021)** | 64.1 % | 16.8 % | 48.6 % |
| **Electricity access** | 100 % (2020) | Total population: 14 %<br>Urban areas: 71 %<br>Rural areas: 2 %<br>(2019) | Total population: 71 %<br>Urban areas: 94 %<br>Rural areas: 50 %<br>(2019) |
| **Electricity from fossil fuels (of total installed capacity)** | 68 % (2020) | 95 % (2016) | 82 % (2016) |
| **Electricity from renewable energy sources (as of 2017)**[57] | 31 % | 5 % | 18 % |
| **Electric power consumption (kWh per capita; as of 2014)** | 904,000 | 51,200 | 229,400 |

Notes: * = This includes the contested territory of the Western Sahara; ** = This does not include the contested territory of the Western Sahara.
Source: CIA( 2021a, 2021b, 2021c), World Bank (2022a, 2022b, 2022c).

[56] Data points are in 2017 dollars.
[57] Including hydropower. Without: 15 %, 5 % and 11 % respectively.

## 6.1 Morocco

### 6.1.1 Geographic and energy-related overview of the country

Morocco is often considered a forerunner of climate and renewable energy policy in North Africa. With the world's largest concentrated solar power plant project in Ouarzazate located in the country and a target of 52 % installed renewable energy capacity by 2030 (Kingdom of Morocco, 2016), Morocco is placed at rank eight of Germanwatch's Climate Change Performance Index 2022, for example (Burck et al., 2022).

Morocco has scaled up its renewable energy generation capacity significantly. At the end of 2020, 40 % of the total installed electricity generation capacity were from renewables (IEA, 2021c), and 20 % of electricity was generated from renewable energy sources. 4 % of grid electricity came from solar facilities (1,581 GWh), 12 % from wind power (4,587 GWh) and 4 % from hydropower (1,654 GWh) (EcoActu, 2020; Our World in Data, 2022).[58] The larger share of Morocco's electricity production – around 75 % – is still generated by burning coal or gas – the absolute electricity generation in GWh from coal has more than doubled since 2013 (IEA, 2021c).

In the long term, Morocco has embarked on a path of decarbonization (CAT, 2021b). Despite the inclusion of additional natural gas infrastructure in its newest Nationally Determined Contribution (NDC; Royaume du Maroc, 2021) and the lack of a net-zero target, Morocco is still one of the few countries whose NDC has been considered "1.5°C Paris Agreement compatible" (CAT, 2021): The country aims to reduce its greenhouse gas (GHG) emissions unconditionally by 18.3 % below business-as-usual (BAU) by 2030, and conditionally (with international support) by 45 % below BAU by 2030 (CAT, 2021). According to official numbers that exclude the occupied territory of Western Sahara, Morocco's electrification rate is 100 % as of 2020, including rural areas (CIA, 2021c). Due to its close proximity to the Iberian Peninsula and the long-lasting (colonial) ties to France, more than 40 % of all of Morocco's exports of commodities are destined for France and Spain alone, but only 20 % of its imports of commodities come from these two countries as of 2017. The exported commodities range from cars over fertilizers and agricultural produce to clothing and apparel (CIA, 2021c), but also include small amounts of (coal-based) electricity to Spain, by undersea cable (Monnet, 2019). As of 2015, these exports did not exceed 165 GWh, whilst Morocco imported more than 5,000 GWh of electricity (CIA, 2021c).

Undoubtedly, Morocco is ahead of Niger or Senegal in terms of exporting hydrogen: the country on Europe's doorstep has passed its long expected National Hydrogen Strategy in late 2021, building on its National Hydrogen Commission in 2019 and green hydrogen roadmap from January 2021 (Ministère de la transition énergétique et du développement durable,

[58] However, between 2012 and 2015 alone, electricity production from renewable sources (excluding hydroelectric) tripled in the country.

2021). Moreover, according to IRENA (2022a), hydrogen (across the color spectrum) is considered a key growth sector in the national economy – by 2030, the country envisages a local hydrogen market of 4 TWh and an export market of 10 TWh, which would require the construction of 6 GW of new installed renewable electricity production capacity, supporting the creation of more than 15,000 direct and indirect jobs (The North Africa Post, 2022).[59] As early as 2025, Morocco is set to produce approximately 10,000 t of green hydrogen/a, equaling approximately 0.33 TWh),[60] (The Africa Report, 2021) and up to 4 % of the world's green hydrogen demand by 2030 (Eichhammer et al., 2019; p. 57).

Official numbers regarding Morocco's future domestic demand for hydrogen are not yet publicly available. However, the country makes no secret of the fact that it aims to become the world's market leader in the production of green hydrogen (Baumann, 2021). With its Green Hydrogen Cluster, the Moroccan government aims to promote collaboration among private and academic stakeholders to support the emerging renewable hydrogen sector in general, and specifically a collaboration in technology development and the positioning Morocco as a potential exporting hub, by building international partnerships with countries such as Germany and Portugal (IEA, 2021b), e.g., the German-Moroccan Memorandum of Understanding agreed on in 2020 (see Table 3).

The freshwater needed to produce (green) hydrogen could be provided by water desalination plants of which Morocco already has built several across the country, though to address freshwater scarcity (Mebtoul, 2020). Recently, Morocco commenced the construction of the world largest seawater desalination plant, which will be powered by wind energy, near Agadir in the south of Morocco (Construction Review Online 2021). It is expected to have a treatment capacity of 75 million m$^3$ of water/a, equaling 450,000 m$^3$ desalinated water per day at peak as drinking water to the people of the region and for irrigating land (Construction Review Online 2021).

### 6.1.2 Challenges in the country

Though water desalination plants are an option to address the need for freshwater to produce hydrogen it should be stressed that these plants produce brine, i.e. waste water loaded with salt and chemicals, so ecological harm could arise from its return to the sea (IRENA, 2022b).

Whilst more than 98 % of Morocco's urban population has access to drinking water, only 79 % of its rural population have (CIA, 2021c). This must be considered when discussing Morocco's aims to export green hydrogen in large quantities. German development aid is working on the sector as are many other actors. For example, KfW is supporting the expansion of water supply and sanitation for the remote hinterland of Morocco on behalf of the German Federal Ministry for Economic Cooperation and Development (KfW, 2020). Another problem in Moroccan

[59] Summarising Morocco's Green Hydrogen Roadmap (Royaume du Maroc, 2021b).
[60] See some rules of thumb on the website Carbon Commentary (2021).

water management is the low efficiency of water use, with up to 4,790 million m³ lost annually due to various factors. The losses could be reduced by about 2,300 million m³ (Umweltradar, 2021). By way of comparison the electrolyser needs are not that large: while at least 300,000 m³ of water would be needed to produce the amount of hydrogen envisaged from the Moroccan government (14 TWh of which 4 TWh for own consumption and 10 TWh for export), this is an order of magnitude less than the current losses.

Another important, though more political point relates to the occupied territory of Western Sahara. Any (green) hydrogen-related project in this territory would obviously be politically sensitive. At this point, the German-Moroccan Hydrogen Partnership has been temporarily suspended and is under review due to diplomatic tensions arising from Germany's public support for the sovereignty of the Western Sahara (Sanz, 2021). The nationalist liberation movement claiming the Western Sahara (Polisario) has recently accused Morocco of the exploitation of Western Sahara’s wind and solar power, in order to reach its goal of getting 53 % of its energy from renewables by 2030 as well as to power its phosphate, desalination and airport industries (Lo, 2021).[61]

Another challenge for bilateral cooperation between Morocco and Germany is the diplomatic relationship between the two countries, which has become strained in the process. After a unilateral break-off of contact on the part of Morocco in the spring of 2021, the first rapprochements are now taking place again after the German change of government in 2021 (DW, 2021).

### 6.1.3 Summary

Figure 9 sums up the strengths, weaknesses, opportunities and threats (SWOT) for green hydrogen in Morocco. Our assessment is convergent with that of IRENA (2022a), Jensterle et al. (2019) and others that Morocco indeed has a huge potential (one of the world’s highest) to become a major green hydrogen producer. As we have seen, the water-related challenges seem manageable. However, the occupied territory of Western Sahara remains a sensitive issue, together with the construction and running of seawater desalination plants. If Morocco wants to spearhead the production of and export from green hydrogen in (North) Africa, land use issues will have to be resolved by including all relevant stakeholders and ensure that local communities profit first. Lessons learned from the Ouarzazate concentrated solar power plant should be applied such as the need for planning (mega) power plants and desalinations plants together with local communities (Baumann, 2021) as well as the importance of technology diffusion and linked with it local capacity building.

[61] Similarly, while climatic data referred to in Morocco’s NDC suggests there has been no long-term, Western Sahara-wide decline in rainfall, a leader of Polisario recently stated that it had not rained in most parts of Western Sahara for about five or six years (Lo, 2021).

Figure 9: SWOT analysis of Morocco's potential to produce and export green and fair hydrogen to Germany

| Strengths | Weaknesses |
|---|---|
| • High area and generation potential for RE and hydrogen<br>• Possibility for hybrid systems Wind/PV offer potential for very high full load hours<br>• Within pipeline radius of EU and Germany<br>• Political ambition to become a pioneer in renewable energy expansion and leading green hydrogen exporter | • Arid desert state, therefore, necessity to desalinate seawater (additional energy/electricity demand)<br>• Long distance, high transport costs to Germany<br>• Need for expansion of energy infrastructure<br>• Autocratic system<br>• Currently high dependence on fossil energies |
| **Opportunities** | **Threats** |
| • High potential for local value creation both in Morocco (through production) and in Germany (through hydrogen plant export).<br>• Starting point for energy networking with other countries in the region<br>• Synergy effects for own supply of drinking water, renewable energy, and raw materials<br>• Hydrogen partnership with Germany<br>• Various energy- and hydrogen-related partnerships with Germany and the EU already agreed on | • Delays in the expansion of renewable energies, hydrogen production and infrastructure - jeopardizing or failing to meet own renewable energy and hydrogen targets as well as local energy and water supply (through hydrogen exports).<br>• Lack of acceptance for hydrogen exports<br>• Geopolitical conflicts, such as the current one over the Western Sahara, can impair the hydrogen partnership with Germany.<br>• Possible Changes in strategy Drought and water scarcity or competition for water use. |

Source: Own illustration; own translation, based on SCI4climate.NRW et al. (2021, p. 13).

## 6.2 Niger

One of the world's poorest countries by several measures (CIA, 2021a), Niger is faced with a number of challenges in the attempt to produce green hydrogen.

### 6.2.1 Geographic and energy-related overview of the country

Niger is rich in conventional energy resources. It is considered an 'oil resource center' by the IEA and is one of the ten largest uranium resource holders in the world (IEA, 2021d). Specifically, France – the country with the world's largest share of nuclear energy (Statista, 2021) – has been importing a significant share of its uranium need from its former colony (Tertrais, 2014). Niger also exports refined petroleum products as well as gold.

Biofuels and waste constitute the sources of energy for most people in Niger (IEA, 2021d), whilst 95 % of its electricity is produced by burning fossil fuels and only 5 % stem from renewable energy (CIA, 2021a). Thus, despite the lack of renewable electricity generation capacity in the country (e.g. hydropower, solar PV, wind) Niger's energy sector accounts for less than 9 % of the country's total GHG emissions (Republic of Niger, 2015). Niger's most recent NDC confirms that around 90 % of all GHG emissions are due to land use, land use change and forestry as well as agriculture (Republic of Niger, 2015). In its NDC, Niger focuses on co-benefits, marrying mitigation and adaptation efforts, visioning "climatically intelligent agriculture and [...] access to modern energy services for everyone in 2030" (Republic of Niger, 2015; p. 5).

Niger has set up its own agency – The Niger Agency for the Promotion of Rural Electrification – which has developed ambitious goals to bring clean energy to rural areas (PowerAfrica, 2020). But as of 2019, Niger still had a long way to go in terms of electricity access to its population. Whilst 71 % of urban areas were electrified, only 2 % in rural areas were. Thus, only every seventh person in the rural-dominated country had access to electricity in 2019 (IEA, 2021d). For 2030, Niger aims to improve these rates to 100 % and 30 % respectively, amounting to 60 % in total (Republic of Niger, 2015). Currently, the country still relies to a significant extent on electricity imports,[62] which have increased steadily over the last 20 years (IEA, 2021d).

In addition to increasing electricity access, Niger is also striving to increase the share of renewable energy sources in its electricity mix, from 10 MW installed power generation capacity in 2010 to 250 MW in 2030, via constructing one large hydropower plant along the Niger River (Republic of Niger, 2015), the World Bank backed Kandadji dam close to the border with Mali (World Bank, 2020). Niger is in the process of awarding a contract for building a 50 MW solar photovoltaic plant near the capital Niamey under the International Finance Corporation's 'Scaling Solar' programme (Takouleu, 2022).

### 6.2.2 Challenges in the country

Judging from the data analyzed for the $H_2$-Atlas Africa, Niger has a very high technical potential to produce hydrogen (more than 16 kWh/(a*m$^2$), especially in the North-East). Solar PV could be generated most cheaply in Niger's north-east at costs getting of EUR 2.3-2.8 cents (ct)/kWh and onshore wind for EUR 2.1-6.4 ct/kWh (north-eastern fringe) to EUR 6.4-10.7 ct/kWh (most of the rest of the country) (FZ Jülich, 2022).

But around 20 % of its area are not eligible for the development of onshore wind, and this figure is even higher for solar PV. Specifically, large areas in the southern part of the country

[62] 3/4 from Nigeria alone under a preferential of about USD 4 ct/kWh (World Bank, 2015).

are excluded as other land uses or protected areas prevail here.[63] The areas suited for the generation of renewable electricity need to be selected and developed very carefully and it can be expected that the areas that are not subject to competing land uses are far away from most infrastructure, including roads, in the deserts of the North East.

In addition, apart from Niger's South, the whole country faces water scarcity issues as of now.[64] There, in turn, the costs to produce hydrogen would be higher due to higher levelized costs of electricity (FZ Jülich, 2022). While that area is located closer to the Gulf of Guinea and better linked to transportation infrastructure, which could lead to decreasing transportation costs to ports for hydrogen shipping, the North is potentially better placed for transport by pipeline. Both means of transportation remain very challenging and require a build-up of new infrastructure.

In its NDC, Niger states the intention to "[d]ouble the rate of [renewable] energy […] to reach 30 % energy mix in the primary and final energy balance" (Republic of Niger, 2015; p. 2). For that, Niger would require a six-fold increase by 2030, and any electricity used for hydrogen production would need to be additional to that.

Considering the large needs for freshwater for both agriculture and uranium production, producing hydrogen which equally relies on fresh water might, in general, not seem a good choice for the landlocked country that already experiences high water stress levels (IRENA, 2022a).[65]

This becomes even clearer considering the security situation in Niger. The extraction and transport of uranium in Niger has been requiring private security firms and even special forces (both Nigerien and French) for many years, first initiated by the hostage-taking of five French citizens in the Sahel in 2010 and the constant threat of Islamist attacks (BBC, 2010, 2013). Arguably, the same threat looms large for foreign technical specialists coming to Niger to work on gas or hydrogen pipelines.

Though information on the costs for these security measures is scarce, one might also raise the question how Niger would protect hydrogen pipelines of presumably many hundreds of kilometers length from terrorists. This question is particularly interesting in light of the experiences around the Trans-Saharan Gas Pipeline. Planned since the 1970s and put on hold in recent years – among other things because of security fears in northern Niger (Majeed, 2021; The North Africa Post, 2017) – construction is set to continue with the

[63] 'Excluded areas' are defined in the H2-Atlas Africa as such areas where an initial, detailed land analysis took into account several socio-political, physical and ecological restrictions (e.g., settlements, water surfaces or nature conservation).

[64] Measured by FZ Jülich (2021a) as hydrogen (potential) producible from groundwater (in %) and hydrogen producible from groundwater per area (in $kWh/(a*m^2)$).

[65] However, IRENA projects that by 2050, global hydrogen production will still be less than 1 % of today's agricultural water consumption, and only 2/3 of today's desalination production (IRENA, 2022; p. 98).

Declaration of Niamey[66] in mid-February 2022 (African Business, 2022). Security aspects are, are as of now, not considered in the $H_2$-Atlas Africa, which analyses the feasibility of large-scale (green) hydrogen projects in Niger by drawing on technical (and some social) indicators alone. From that perspective, the area around the capital Niamey in Niger's South-West is widely considered the safest one, but from the physical geography-factors considered in the $H_2$-Atlas Africa, of marginal use for producing green hydrogen (FZ Jülich, 2022).

### 6.2.3 Summary

In the light of these aspects and the less than optimal natural conditions (best groundwater availability in the South-West, highest hydrogen production potential in the Centre and North), it becomes clear why Niger is not mentioned among the “particularly suitable countries of origin” in a comprehensive study examining the most suitable countries for Germany to import green hydrogen from by 2030 (Jensterle et al., 2019). The low levels of availability of renewable electricity and the high domestic needs for additional capacity would require significant scale-up in the energy sector to satisfy domestic demand before adding electricity generation capacity for export-focused hydrogen production. Potentially, island solutions could be considered, under preconditions complying to the criteria system developed below.

Producing and exporting green hydrogen could undoubtedly have great local and regional economic importance, not least in the light of the urgently needed diversification of Niger's exports, including of its uranium sector. As we have seen, only a comparatively small area of Niger (surrounding the capital Niamey) would be able to produce both renewable electricity and green hydrogen without impeding local population needs. Despite these challenges, Niger is engaging in the hydrogen economy. For example, a project to carry out a feasibility study to examine suitable sites for green hydrogen production with a German energy promoter was announced in early 2022 (DGAP-News, 2022).

The SWOT analysis in Figure 10 illustrates that producing ‘fair green hydrogen’ in Niger still has a long way to go, based on what was presented in this chapter as well as derived from Figure 4 and Figure 5.

[66] Signed by Niger, Algeria and Nigeria on occasion of the third Mining and Petroleum Forum of the Economic Communities of West African States with the concrete aim of reviving the multi-billion-dollar Trans-Saharan Gas Pipeline project (African Business, 2022).

Figure 10: SWOT analysis of Niger's potential to produce and export green hydrogen to Germany

| Strengths | Weaknesses |
|---|---|
| • High area and generation potential for renewable energy and hydrogen in vast parts of the country<br>• Comparatively little costs for producing hydrogen in some parts of the country | • Arid, landlocked desert country, desalination absolutely necessary (additional energy/electricity demand/power requirements)<br>• Periodic droughts and desertification of on-desert portions of the country<br>• Long distance, high transport costs<br>• No direct access to the sea<br>• Need for expansion of energy infrastructure<br>• Currently high dependence on fossil energies<br>• Still reliant on electricity imports for a significant share of its supply |
| **Opportunities** | **Threats** |
| • Some potential for local value creation in Niger (through production), more potential in Germany (through plant export)<br>• Created local jobs might mitigate loss of jobs due to prospective closure of uranium mines to some extent<br>• Existing partnership with Germany as part of WASCAL (training of future engineers) | • Delays in the expansion of renewable energies, hydrogen production and infrastructure - jeopardizing or failing to meet own RE and hydrogen targets as well as energy and water supply (through hydrogen exports)<br>• Act of Islamist terrorism could disrupt supply chains of green hydrogen or impair an emerging partnership with Germany<br>• Changes in government and strategy, including the surge to power of Islamist groups<br>• Drought and water scarcity<br>• Competition between own supply of drinking water, renewable energy, and raw materials |

Source: Own illustration.

## 6.3 Senegal

### 6.3.1 Geographic and energy-related overview of the country

So far, Senegal's electricity generation is mainly based on oil and coal (82 %), with the absolute use of coal having more than doubled since 2017. Renewable energy plays a small role in Senegal's electricity mix (11 %) though solar generation skyrocketed from a very low base level in 2016 (6 GWh) to 2019 (almost 300 GWh).[67] In direct comparison, Senegal is more oil-dependent than Niger (IEA, 2021e).

Under the current president, Macky Sall, Senegal has experienced unprecedented growth from exporting its oil and gas resources: revenues from its hydrocarbon sectors increased by almost 40 % between 2018 and 2019 alone (up to USD 42.5 million) (Goosen, 2021). In fact, the hype around its oil and gas industry is so great that Senegal is positioning itself to compete on the international oil market, with major investments in maritime infrastructure, such as the launch of the Port of the Future project, a USD 1.1 bn superport located 50 km southeast of its capital Dakar (Hundermark, 2021).

Other superlatives purport the country's focus on hydrocarbons as well: Senegal already hosts two of the largest oil and gas projects in Africa – including the continent's deepest offshore project –, with commissioning scheduled for 2023. Against this background the governmental view on natural gas is that of a transition resource that is essential for Senegal's energy transition whilst spurring economic growth and maintaining regional security (Goosen, 2021).

But still, Senegal is not energy independent. Natural gas was first discovered in 1997 and has been exploited since 2001.[68] Using almost 60 million m$^3$ of natural gas for domestic consumption in 2017, Senegal neither imported nor exported any natural gas. While in 2015, the country did not export any crude oil, Senegal imported 17,880 barrels of crude oil per day. Domestic production of refined petroleum products was 17,590 bbl/day as of 2015, but its domestic consumption of refined petroleum products is three times as much. Thus, Senegal still had to import 2/3 of its consumption of refined petroleum products as of 2015 (CIA, 2021b).

In sharp contrast to its oil and gas projects and targets, the country's first-ever NDC, submitted in 2020, aims for an unconditional reduction of its GHG emissions by 5 % and 7 % by 2025 and 2030 respectively, compared to "Business-as-usual". These relative reductions could be increased to 23 % and 29 % by 2025 and 2030 respectively, compared to "Business-as-usual", if Senegal: (1) receives support from the international community with substantial funding; (2) receives facilitation of the transfer of environmentally sound technologies and capacity and (3) if its institutional and human capacities in the field of climate change are strengthened.

[67] For a brief overview about Senegal's (solar) energy policy, see (Energy Capital & Power, 2019).

[68] By the American company Fortesa.

The NDC measures related to renewable energy sources are listed in Table 7. Senegal's estimated costs for the unconditional and conditional targets are USD 4.8 bn and USD 8.2 bn respectively, summing up to USD 13 bn (Republique du Senegal, 2020) for both, climate mitigation and adaptation to climate change.

As of now (March 2022), no projections about Senegal's own future domestic demand for (green) hydrogen are publicly available. Such a scenario would be an important information for negotiating the Bilateral Energy Partnership with Germany, which is about to be signed soon (Ehlerding, 2022).

Table 7: Senegal's mitigation measures via renewable energy sources at a glance

| Unconditional renewable energy measures | Conditional renewable energy measures |
|---|---|
| Achieving an additional installed capacity of 100 MW in solar, 100 MW in wind, 50 MW biomass, 50 MW of concentrated solar power, by 2030 | Achieving a cumulative installed capacity in solar of 235 MW, 150 MW in wind, 314 MW in hydroelectricity in 2030 |
| Injection of a total additional renewable energy capacity of 300 MW, bringing the total (conditional and unconditional) to 999 MW in renewable energy | Injection of a total power of 699 MW in renewable energies in 2030 |
| Replacement of fuel oil by natural gas in dual thermal power plants (oil/gas) and of the 320 MW Jindal coal-fired power plant by combined cycle gas power plants, bringing the total installed capacity of natural gas to 600 MW between 2025 and 2030 | Achieving a penetration rate of renewable energy of 13.68 % in installed capacity, excluding hydroelectricity, in 2019 in the electricity grid |
| Achieving a share of 18 % of renewable energies, excluding hydroelectricity, in the electricity system by 2022 | The installation of 6,18 MWp within the framework of the promotion of the electrification by solar, at the level of the isolated systems out of Interconnected Network |
| Rural electrification by solar energy in 2025 of:<br>• 2292 localities by mini networks<br>• 4356 locations Solar Home System | Improving the energy efficiency of the energy, transportation, and residential sub-sectors |

Notes: * = Non-renewable energy mitigation measures cannot be stated in greater detail at this point.
Source: Own illustration, based on Republique du Senegal (2020); own translation.

### 6.3.2 Challenges in the country

As of 2019, electricity access in Senegal is significantly higher than in Niger but still less than Morocco. 94 % of urban areas and 50 % of rural areas are connected to the grid, bringing the total to 71 % (CIA, 2021b).

Despite its large solar potential, some pioneering projects and legal measures (e.g. value-added tax exemption for renewable energy materials) to support the renewable energy sector, there are still major institutional and structural hurdles to overcome for a breakthrough of renewable energy (BMWK, 2022).

Similar to Niger, Senegal faces the problem that in the areas with the highest technical hydrogen potential per area (kWh/(a*m$^2$),[69] i.e., the country's northern and north-eastern fringe, almost no groundwater is available. So far, there are hardly any ground water conflicts in the country. According to the $H_2$-Atlas Africa (FZ Jülich, 2022), some areas of Senegal are close to 90-100 % hydrogen producible from groundwater, whilst others (especially in the country's western half) are close to 0 %.[70]

In terms of restrictions, around half the country is excluded for onshore wind turbines, including large chunks of the country's east.[71] Not much area is available for offshore wind around Senegal's coastal capital Dakar, but more towards the southern coastal strip of the country – where the levelized costs of electricity, in turn, can be considered high. Only central and central-east Senegal's area is available for solar PV with hardly any costs in the country's most eastern fringe (2.8-3.2 ct/kWh) (FZ Jülich, 2022).

Some cross-border challenges for natural gas are likely to arise and remain: The gas discoveries resulting in the Greater Tortue Ahmeyim project[72] are located on both sides of the maritime border between Senegal and its neighboring state of Mauritania. Thus, the project could turn into a prime example of how two countries can cooperate in co-developing joint natural resources (Artacho, 2021; BP, 2017) and potential learnings for regional cooperation on (green) hydrogen be derived.

#### 6.3.3 Summary

The SWOT analysis in Figure 11 illustrates that producing 'fair green hydrogen' production may be closer to starting in Senegal than Niger at this stage, but is still far behind Morocco (see also Figure 4 and Figure 5).

[69] Defined by FZ Jülich (2021a) as the theoretically producible amount of hydrogen for each NUTS 2-3 region (Nomenclature of territorial units for statistics), divided by the region area. The calculated potential is only limited by the land eligibility constraints as well as the available power limited by energy intake.

[70] Defined by FZ Jülich (2021a) as the producible share of the theoretical hydrogen potential if water availability is taken into account. The range is between the minimum of 0 % and the maximum of 100 % theoretical potential that can be produced with sustainable ground water reserves (limited by energy availability).

[71] According to FZ Jülich (2022), these are "[a]reas not eligible for the erection of onshore wind turbines due to several exclusion factors and safety buffers considered in a detailed land eligibility analysis."

[72] Made from 2015 onwards mostly by the American firm Kosmos Energy and the British giant BP as well as the national companies Petrosen (Senegal) and Société Mauritanienne des Hydrocarbures (Artacho, 2021; BP, 2017).

Figure 11: SWOT analysis of Senegal's potential to produce and export green hydrogen to Germany

| Strengths | Weaknesses |
|---|---|
| • Possibility for hybrid systems Wind/PV offer potential for very high full load hours<br>• Coastal country often dubbed as "Gateway to Africa" for its many maritime travel/shipping routes | • Long distance, high transport costs via shipping<br>• Need for expansion of energy infrastructure<br>• Currently high and further increasing dependence on fossil energies<br>• Need to build many desalination plants following the 'additionality principle' |
| **Opportunities** | **Threats** |
| • Medium area and generation potential for RE and hydrogen<br>• Some potential for local value creation in Senegal (through production), more potential in Germany (through plant export).<br>• Starting point for energy networking with other countries in the region<br>• Synergy effects for own supply of drinking water and renewable energy and raw materials | • Delays in the expansion of renewable energies, hydrogen production and infrastructure - jeopardizing or failing to meet own RE and hydrogen targets as well as energy and water supply (through hydrogen exports)<br>• Low acceptance of hydrogen-projects as hydrogen exports are not even discussed widely yet<br>• Drought and water scarcity in some areas or competition for water use |

Source: Own illustration.

Overall, due to its coastal location and higher water, the generation of renewable energy-based electricity and production of green hydrogen is mostly determined by the (restricted) available land. As large areas are excluded for onshore wind energy, for example, Senegal's vast offshore wind potential (FZ Jülich, 2022) might become more attractive and accompany (if not substitute) the ongoing oil and gas 'hype' in the country. Seawater desalination plants would and could have to be built to allow for electrolysis in the first place and be ensured that they profit first and foremost local communities by providing drinking water. Shipping instead of (hydrogen) pipelines could allow for rather quick hydrogen exports but would most likely render green hydrogen 'Made in Senegal' more expensive than, say, that of Morocco. Similar to Niger, however, local energy supply and access to renewable electricity for domestic consumption would still need to receive priority before utilizing the power for hydrogen production.

## 6.4 Summary and Outlook

As we have seen across the three case studies, ecological factors and social concerns will continue to prove a major barrier to scaling up green hydrogen infrastructure – as long as the government takes them into account – as well as their points of overlap, especially the need for and waste products of desalination plants.[73] Morocco has both the highest potential and ability to both produce and export green hydrogen in the near- to mid-term future. Tellingly, in mid-February 2022 the EU unveiled plans to invest EUR 1.6 bn in Morocco as part of the EU's EUR 300 bn 'Global Gateway' infrastructure plan, Europe's first-ever African scheme and response to China's Belt and Road Initiative (DW, 2022).

In Morocco it has to be ensured that its own population benefits directly from both (new) desalination plants as well as economically from the current hydrogen boom. This can only be ensured if the necessary increase of the renewable energy-share in the domestic electricity mix does not automatically translate into immediate exports of green hydrogen.

For Niger it is hard to imagine that in the near-to medium-term future, green hydrogen could be produced in a 'fair' way or easily be transported to the South (to Nigerian port facilities) or to the North through pipelines to Algeria and then further to Europe. Given the time, material, cost, and logistical challenges involved, Niger is not currently a competitive location for green hydrogen production, despite the country's vast solar and wind resources. If the country decides – and there could be good reasons for it – to invest in hydrogen production plants, questions of infrastructural connection, power availability and water availability must first be clarified. Green hydrogen production is more difficult compared to other locations in Africa, but not impossible.

In Senegal, as well, the hydrogen economy will not be a no-brainer. It is not impossible that (green) hydrogen follows the model of 'enclave production', i.e., of extraction[74] and export that is piloted by the oil industry. Senegal – like many other countries of the Global South – has sold its own resources in trade relationships mostly dominated by European countries rather than integrating its value chain. Senegal exports modest amounts of crude oil (worth USD 20.2 million in 2019), but imports huge amounts of crude oil worth the 20-fold (OEC, 2022) and imports eight times the amount of refined petroleum products that it exports (CIA, 2021b). Large population groups likely have hardly benefited from the vast natural resources of the coastal country. For green hydrogen to not perpetuate the same pattern, socially and ecologically fair criteria will be inevitable.

Germany already has several initiatives in research cooperation with West African countries, such as WASCAL or the bilateral Master's programme for future hydrogen leaders. Thus, initial capacity building is taking place that can benefit the initiation and implementation of further hydrogen projects. Such cooperation efforts also contribute to raising awareness for the expansion of renewable energy and thus enable green hydrogen production in the medium term.

[73] At the same time, green hydrogen could give a spur to the desalination industry, potentially resulting in a massive scale-up of desalination capacity. This, in turn, could also increase the supply of freshwater for other purposes beyond electrolysis, or drive down the cost of desalination (IRENA, 2022a).
[74] Arguably, „[h]ydrogen is a conversion, not an extraction business", though (IRENA, 2022; p. 10).

Reflecting on these aspects and challenges, as well as the existing safeguards raised in chapter 5, the following chapter highlights the current debate on broader criteria related to the production and trading of green hydrogen and discusses where and how the debate still needs to be broadened with regard to the fairness dimension.

# 7 Criteria sets for sustainable 'Green' Hydrogen

The analysis so far has demonstrated that even with the expected massive ramp-up of the global hydrogen economy and the expected intensification of Germany's cooperation with African partners, there is no guarantee that the production and trade of hydrogen would be able to meet the expected demand. IRENA expects green hydrogen to remain more expensive than blue hydrogen in the three countries until at least the 2030s (IRENA, 2022). However, considering the time frames needed for building and upscaling green hydrogen infrastructure in these countries, it is about time to bring discussions of hydrogen-related criteria to the next level. That is, instead of merely discussing ecological (and to some extent economical) sustainability of hydrogen imports (e.g. NWR, 2021a; Öko-Institut et al., 2021; SRU, 2020), this has to be complemented by aspects of social sustainability, i.e. 'fairness' aspects.

The supply situation for hydrogen is strained, and this enhances the already considerable risk that the hydrogen imports will be associated with the traditional "dirty" practices of the energy and extractives sector, and lead to higher greenhouse gas emissions instead of lower. In the absence of an institutional body and global framework for green hydrogen,[75] no common criteria have been agreed upon that would define 'green hydrogen' in a certifiable way, not to mention 'fair and green hydrogen' nor 'sustainable hydrogen'.

**Box 4: Sustainability**

As a normative vision of the future, sustainability can be considered to encompass "all areas of human life and economic activity" (*Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz* [BMUV], 2021). This explicitly includes economic, environmental, and social dimensions. Thus, social justice is an integral part of sustainable development. Already back in 1987, the Brundtland Report stressed the importance of inter- and intragenerational justice. Although there have been positive developments in many areas, consistent efforts to address the social aspects of environmental and climate policy are still lacking (Reineck et al., 2021).

'Sustainability' in this study will be understood as working towards achieving individual Sustainable Development Goals (SDGs) that were agreed on by the United Nations in 2015, without compromising any other of the 17 SDGs specifically and the Agenda 2030 more

[75] Misleadingly, the Hydrogen Council is only "a global CEO-led initiative of leading companies" (Hydrogen Council, n.d.).

generally. The SDGs, in turn, should not be equalized with 'sustainability' in general but represent a large step in the direction of considering social aspects of sustainability particularly.[76]

There is already a broad debate regarding a 'better' production and trade of green hydrogen, and in the context of this debate, initial criteria and approaches have been formulated. Currently, several sets of criteria for green hydrogen, which take into account sustainable approaches and perspectives are being developed and discussed on a national and international level.[77] From a German perspective, noteworthy contributions have been formulated by Öko-Institut et al. (2021) and the National Hydrogen Council (NWR, 2021). Both discuss potential gaps and finally formulate a further developed set of criteria for 'Fair Green Hydrogen', which should address the problems and challenges raised so far in this study more comprehensively.

## 7.1 Hydrogen-Criteria by Germany's National Hydrogen Council

Germany's National Hydrogen Council (NWR) differentiates between criteria for hydrogen projects and the framework setting at intergovernmental level. Crucially, these recommendations were made after Germany passed its National Hydrogen Strategy (NWS) in 2020. The NWR as an advisory body to the German government has shown no intention yet, to add 'fairness' criteria to Germany's approach to importing hydrogen on top of the 'green' import criteria formulated so far. The following aspects , for both framework setting at intergovernmental level and hydrogen project level, have been proposed (NWR, 2021):

**Framework setting at intergovernmental level**

- Establishment of a certification system suitable for the non-European context
- Embedding of projects in national or regional energy transitions,
- Contribution to combatting energy poverty,
- Emphasis on human rights and anti-corruption standards as well as transparency,
- Ensuring participation of local stakeholders and civil society as well as affected population groups,
- Ensuring that investments from industrialized countries are economically attractive for the exporting country and
- Ensuring local value creation.

[76] Though not exactly the same, in this study 'sustainability' is intended to be equal to 'sustainable development'. Most often and historically defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987).

[77] This study will not look further at the aspect of scarce resources such as metals for electrolysers needed for producing hydrogen (e.g. Johann, 2022). This deserves standalone studies and would certainly add further criteria for producing and exporting 'fair green hydrogen'.

**Hydrogen project level**

- Certified carbon dioxide footprint of hydrogen and its derivatives,
- Carbon dioxide for downstream products must be extracted from the atmosphere,
- Contribution to combatting energy poverty,
- Project-based impact assessments related to ecological, human-rights and social aspects,
- avoidance or resolution of land use conflicts, resettlements or illegal land grab by the projects,
- avoidance of water distribution conflicts and risks for water supply in the context of the projects.

## 7.2 Criteria by Öko-Institut

The criteria put forward by Öko-Institut et al. (2021) focus on sustainability dimensions in the emerging international market for green hydrogen, the production of green hydrogen and its export to the EU. Öko-Institut et al. (2021) conclude that (1) ambitious and clearly defined sustainability criteria help mitigating negative effects of hydrogen production abroad and (2) provide investment security for companies, as they provide a basis for the recognition of imported hydrogen as climate-compatible and aligned to the Paris Agreement in the long run. The authors stress that for an early uptake of sustainable green hydrogen– besides agreeing on criteria –, necessary next steps include the setting ecological standards and the building up of institutions and cooperation structure with future exporting countries.

They develop a set of 18 criteria subsumed under six sustainability dimensions in hydrogen production: (1) electricity supply, (2) water supply, (3) land use, (4) socio-economic impacts, (5) transport, (6) other. The 18 criteria are not discussed in greater detail here, but their overarching rationales stated by Öko-Institut et al. (2021; p. 5) can be summarized as follows:

- Country level: Hydrogen trading partners should be asked to develop decarbonization strategies, taking hydrogen production into account; analyze these strategies through Strategic Environmental Assessment (SEA); and the trading partners' strategies should be adjusted in case the SEA identifies major concerns.

- Project level: An Environmental Impact Assessment (EIA) should be carried out; a Sustainability Impact Assessment could accompany the EIA and include socio-economic dimensions; local stakeholders should be consulted, and suitable grievance mechanisms be implemented.

- Electricity input to hydrogen production: Electricity should be sourced solely from renewable energies; system integration and avoiding grid bottlenecks should be considered if the electricity is sourced from the grid; domestic decarbonization should not be impeded by the allocation of renewable energy to hydrogen production; local sustainable development could be supported by additional investment in local infrastructure (e.g. energy grids, electricity storage systems, renewable electricity generation).

- Water for electrolysis: Water should only be sourced from additional seawater desalination plants; sourcing from surface or ground water should be limited to areas with high water availability; local water prices should be monitored and, in case of increasing prices due to hydrogen production, countermeasures be taken; renewable energies should power the desalination plants; desalination plants should fulfil ecological standards; local sustainable development could be supported by investment in improved water infrastructure (to reduce losses and evaporation) and additional water production through seawater desalination.
- Land-use change: For both, hydrogen production and especially renewable electricity generation, no land-use change should take place in (ecological) protected areas; local and informal land rights should not be violated, ensured by local stakeholder consultation; local sustainable development could be further supported by economic participation of the local population and enabling co-benefits (e.g., agricultural solar photovoltaic systems).
- Socio-economic risks: Human rights violations should be prevented and due diligence procedures (sector-specific risks and adequate measures) should be followed to mitigate socio-economic risks; corruption should be prevented via initiatives defining standards for economic participation and making the flow of money transparent; socio-economic participation could be supported by establishing local supply chains for technology, local capacity building initiatives, direct investments in research and development, and guaranteeing a pre-defined share of local workforce.
- Carbon dioxide: Carbon dioxide is needed to produced hydrocarbons (e.g., kerosine, methanol) from renewable hydrogen. Only those sources with a short-term carbon-cycle with the atmosphere should be used for extracting carbon dioxide: Only use carbon dioxide from direct air capture processes or unavoidable waste streams from industrial processes (based on sustainable biomass).
- Raw materials and transport: Compliance with due diligence and international labor safety standards should be mandated for the whole value chain; overall sustainability impacts of transportation in the exporting country should be kept as low as possible by considering the most efficient mode of transportation.

## 7.3 Discussion

Similar to the National Hydrogen Strategy (NWS) by the German Government (Bundesregierung, 2020), both the German Hydrogen Council (NWR, 2021) and

Öko-Institut et al. (2021) propose the principle of 'additionality'. That is, no existing renewable energy or water infrastructure should be used for producing green hydrogen for export. National decarbonization and development ambitions should be prioritized, and thus only surplus renewable energy and water used for producing and exporting green hydrogen. This means that a build-up of hydrogen production capacities must be subordinate (in terms of time) to the capacity build-up required to achieve the respective national climate neutrality targets.

However, it remains unclear who would be held accountable for this principle,[78] and who would have to pay for constructing the necessary local renewable energy supply in the first place. From a 'fairness viewpoint', however, this would have to be done by the importing country or investor, and technology/knowledge transfer be assured.

The discussed approaches also agree upon the need to look at the energy sector and negotiate the competition between export and local decarbonization ambitions (Öko-Institut et al., 2021), or embed the hydrogen development in an energy transition strategy (NWR, 2021).[79] Tellingly, the German Government does not list such a measure in the NWS, focusing instead of country-level cooperation, particularly via existing Bilateral Energy Partnerships and within development cooperation, and aligned with the efforts of the EU (Bundesregierung, 2020).

Where there is lacking local participation and local value creation (Bundesregierung, 2020), grievance mechanisms (as recommended by, for example, Öko-Institut et al. (2021) seem all the more important in order to prevent neo-colonial, exploitative practices from (re-)occurring. The same holds true for exclusion criteria: Surface and ground water in areas with regional water stress must not be used for hydrogen production. Similarly, (ecological) protected areas and areas with contested or informal land rights should be excluded, in order to avoid playing nature, people and climate off against each other.

Furthermore, strict guidance by human rights and SDGs should be required.[80] Öko-Institut et al. (2021) makes these points explicit. However, it has to be stressed that even their criteria are still far from preventing 'green' neo-colonial practices as such, as they only demand, for example, "provisions for additional (funds for) infrastructure [...]", enabling co-benefits such as local economic participation or "[s]ecur[ing] a share of local work force".

While Öko-Institut et al.'s (2021) criteria can be considered the most progressive criteria scheme at this point, they do not sufficiently address the potential impacts of hydrogen production plants on local social and political systems. As we have seen in chapter 6, the challenges but also opportunities of green hydrogen vary significantly across the three case

[78] The measure is restricted by the circumstance that the principle of additionality will only "attention […] be paid to."

[79] More details on this and other proposed criteria can be found in the annex.

[80] Arguably, the SDGs themselves are not free of critique such as their lack of mentioning fossil fuels and their subsidies.

studies. For example, whilst Morocco can draw on a vast range of experiences with international donors and funders for large-scale energy projects such as the solar complex in Ouarzazate, the same can hardly be said for Niger. Consequently, criteria such as the ability of a country to steer development dialogues and investment flows can be considered necessary for speaking of 'fair green hydrogen' projects on country level.

On another note, as was shown especially with the case study on Niger, criteria such as ensuring human rights or international labor standards can only be minimum standards (as proposed by Öko-Institut et al., 2021). In order to speak of 'fair green hydrogen', not only should potentially detrimental local effects of labor or on the environment be mitigated, but positive effects for the local population and region be actively aimed for. That is against the background of the future hydrogen dependency of countries of the Global North such as Germany on countries of the Global South, besides the historic responsibility of (now) developed countries for causing the climate crisis. Building on a discussion how hydrogen investments can exacerbate inequities, we will derive 'fairness' criteria in the next step.

Summarizing, while the sets of criteria presented by the Öko-Institut and the NWR already add some further components to the technical dimension of green hydrogen and thus expand the debate around the sustainability of green hydrogen, the sets of criteria presented do not go far enough. The criteria presented are not fully suited to adequately address the potential neo-colonialist challenges and the case studies. In particular, the issue of social sustainability needs to be given greater consideration and formulated in an advanced approach criteria set.

# 8 'Fair Green Hydrogen' – a refined criteria approach

Current sets of criteria are still insufficiently addressing the challenges and potential problems associated with the emergence of a global hydrogen market and infrastructure and with partnership relations between the Global North and the Global South. This is surprising given that ever-higher amounts of private and public money are flowing into hydrogen projects globally. For example, the German government provides a total of EUR 9 bn by 2030 in order to achieve its deployment target of 5 GW electrolysis (or 10 GW according to the coalition agreement), with EUR 2 bn for international partnerships alone (Bundesregierung, 2020). By way of comparison: As the IEA calculates in its Global Hydrogen Review 2021, by 2030 investments adding up to USD 1,200 bn in so-called 'low-carbon' hydrogen supply[81] would be needed in order to put the hydrogen sector on track to net zero emissions by 2050 – more than a hundred times the amount of what Germany promised so far. In the next step, criteria for 'fair green hydrogen' will be derived, based on the discussion so far. This study therefore

[81] NB: The IEA does not speak of 'green hydrogen', thus including, among others, natural gas, and nuclear power-based hydrogen in its calculation.

provides guiding principles as well as a concrete set of criteria for Fair Green Hydrogen, with which the foreseeable problems can be prevented.

In order to speak of ‘fair green hydrogen’, not only should potentially detrimental local effects of labor or on the environment be mitigated, but positive effects of the local population and region be actively aimed for. That is against the background of the future hydrogen dependency of countries of the Global North such as Germany on countries of the Global South, besides the historic responsibility of (now) developed countries for causing the climate crisis. From the discussion how hydrogen investments can exacerbate inequities, we will derive further ‘fairness’ criteria in the next step.

‘Fair Green Hydrogen’ requires that the needs of the population as well as the decarbonization pathways of the exporting countries must be the starting point of a sustainable import strategy. In other words, ‘fair’ in this study is understood as the combination of sustainability criteria (environmental, economic, social), the prevention of (potentially emerging) neo-colonial practices, structures, and statuses as well as operations for the benefits of local populations and regions, both in absolute and relative terms. Our focus on social aspects of sustainability is the reason why the use of ‘fair’ is preferred over similar terms that are less connected to sustainability thinking as such (e.g., ‘socially equitable’).

## 8.1 Guiding principle (I): Additionality and Do no Harm

In order to minimize the risk of re-establishing or re-enforcing neo-colonial and imperialist practices in the context of a massive investment rush when establishing the global hydrogen economy, one option is to tie the imports of hydrogen to criteria that are highly ambitious and conscientious about these risks. Such criteria can be developed based on existing approaches and standards, with additional standards and safeguards tightening relevant aspects and adding relevant dimensions. The discussions in this study so far, served to derive the following guiding principles:

- Hydrogen production must not take place at the expense of the country's development.
- Hydrogen production must not exclude the Global South.
- If the Global South is integrated into hydrogen production, this has to be done on an equal footing.
- Development of hydrogen production in Global South countries must support their independence and own capacities.
- The use of green hydrogen is needed to achieve decarbonization targets everywhere on the globe. The $CO_2$ reductions achieved through the use of green hydrogen must be fairly distributed between importing and exporting countries, so that importing countries do not achieve their reduction targets at the expense of exporting countries

(who might then be forced to burn additional fossil fuels or incur higher costs). Wherever possible, local decarbonization in countries of the Global North should be preferred over exporting 'carbon solutions' such as green hydrogen from countries of the Global South.

These go in some dimensions beyond the mere additionality principle that is already acknowledged by e.g., German government advisors like the National Hydrogen Council.

With regard to the sustainability dimension, the SDGs provide useful guidelines. Investment flows should not blindly benefit those who already have but be oriented towards the SDGs. Fairness dimensions exist in positive and quantifiable effects for (at least) the following SDGs and their respective targets:

6: Clean water and sanitation,

7: Affordable and clean energy,

8: Decent work and economic growth,

9: Industry, innovation, and infrastructure,

12: Responsible consumption and production,

13: Climate action,

14: Life below water.

It would be conceivable, for example, that those projects that cover either the most SDGs or the greatest breadth in the spectrum of SDGs would receive awards or funding.

On the political level, any relationship between Germany and Europe on the one side and the countries of the Global South on the other side that includes the export or import of green hydrogen should be aware of the potentially negative factors and be structured accordingly. This means that the relationships and partnerships should be based politically on

(1) the ability, empowerment, incentives and motivation of a country to steer investment flows and development dialogues on all levels (international, national, local) to overcome historical or conventional power relations,

(2) competence and capability transfer,

(3) the creation of economic opportunities in the exporting country,

(4) fair prices (for the hydrogen sold) as well as for the production components and

(5) independence or diversification options for exporting countries (no exclusive rights for importing countries).

From an economic perspective, too, cooperation should be designed in such a way that exploitative structures are prevented, and the interests of foreign economic actors are not at the expense of the local population and its needs. A large part of the value chain of hydrogen production capacities, as early as in the construction phase, should take place locally and in cooperation with local and regional economic actors. The prerequisites for this should be created through appropriate capacity building in the local education, the research sectors and job market (Bezdek, 2019). The $H_2$-Atlas Africa, initiated and supported by the German federal government, makes the strong case for pursuing green hydrogen projects in West Africa (BMBF, 2021; FZ Jülich, 2022). Furthermore, Germany has invested considerably to train the staff that will be required in a few years' time (BMBF, 2021; FZ Jülich, 2021).

So far, neither the German nor European plans, strategies and partnerships cover the foreseeable challenges in a way that could be deemed sufficient to prevent practices of 'green' neo-colonialism. However, both sides of a trade partnership must ensure that structures and actions meet fairness requirements. This is the more important since West Africa has already been dubbed a potential 'global powerhouse' for procuring green hydrogen by Germany's former research minister (BMBF, 2021). Statements equating the West Africa hydrogen generation potential with 1,500 times the Germany's hydrogen need in 2030 (BMBF, 2021) conjure up overly optimistic picture that obscures the structural and political challenges that need to be addressed in the development of such grand objectives. The failure of promised silver-bullet solutions such as Desertec[82] – at least in the form originally envisaged – has shown the mere reliance of (overly optimistic) technological aspects is not sufficient to realize such projects. It is necessary to realistically take stock of all factors to be considered (economic, political, cultural, economic, etc.) and to adopt an approach that prevents negative impacts of this new branch of the economy. This is first and foremost a political process.

## 8.2 Guiding principle (II): 'Additionality 2.0'

In order to ensure the implementation of these guiding principles, the principle of additionality could be expanded into what could be called 'Additionality 2.0'. In reflection of the colonial legacy and the historical responsibility of the Global North for the climate crisis (Evans, n.d.), an extension of the additionality principle (Pototschnig, 2021) could be considered justified from a fairness perspective. The principle of 'Additionality 2.0' could include '+X solutions' for the development of any basic supply services (renewable energies or water purification, etc.) as standard, in order to give 'something' back to the countries of the Global South and to compensate for their structurally and historically justified disadvantage.

'Additionality 2.0' describes accompanying measures to ensure that the development of hydrogen export infrastructure not only does not hinder the development of exporting

[82] Since 2009, when the Desertec Industrial Initiative was founded by several, predominant German enterprises, failed not once, but twice in realising the Desertec idea: (a) to supply Europe, in a large-scale manner, with electricity produced in solar power plants in North Africa and the Arabic peninsula and (b) to contribute to the self-supply of the Middle East North Africa region (Schmitt, 2018). With the current hype of (green) hydrogen, the Desertec idea – once more – is said to be revived (Willis, 2020).

countries, but also guarantees added value for supplier countries. Such accompanying measures could be, for example, additional investments in renewable energy plants and corresponding infrastructure on site, on a relevant scale in addition to those wind or photovoltaic plants that are needed for the electrolysis itself. These would require a correspondingly extended availability of land and water as well as the avoidance of conflicts of use with the local population and biodiversity. Thus, the principle of 'Additionality 2.0' goes beyond a pure "do no harm" approach, and calls for '+X solutions' for hydrogen projects.

'Additionality 2.0' means that before German (or Western) companies start hydrogen projects in African countries (or countries of the Global South more generally), they have to ensure that the infrastructure built directly benefits local communities and regions in various ways. For example, it would be insufficient to ensure that existing desalination plants are not repurposed to provide water for electrolysis instead of drinking water first (i.e., 'do no harm'), and the project developers would have to provide for new freshwater production facilities for their hydrogen production, but in addition to that, they might be required to build additional capacity to provide water for local communities. The same could hold true for renewable energies.

Benchmarks and standards for this 'Additionality 2.0' could be included in international Memoranda of Understanding (MoUs), e.g., as part of (new) Bilateral Hydrogen Partnerships. These MoUs could define percentages (e.g., in terms of investments, water or electricity consumption) that would need to be provided as the +X.

For understanding what would be 'more than' additional with respect to the climate dimension, one benchmark could be national 1.5 C pathways and emission trajectories (for exporters as well as importers of hydrogen). But 'Additionality 2.0' cannot serve to reduce emission reduction commitments to the UNFCCC. For example, across the three case studies, repurposing renewable energies for producing green hydrogen that is exported to Europe would endanger their chances to meet their own domestic climate targets, as long as there is scarcity of installed renewable energy capacity, as it would be conceivable that shortfalls in electricity will be covered by additional fossil capacity (including but not limited to Diesel generators). Even a strong focus on producing and exporting green hydrogen does not automatically translate into decarbonizing countries' own electricity system. In other words, large investment projects in the Global South, specifically with an export-orientation to provide basic commodities for the Global North, reminisce of exploitative economic relationships and practices of the colonial times and the Oil Era. These are to be avoided.

## 8.3 Criteria for 'Fair Green Hydrogen'

Building on and integrating the criteria systems discussed earlier, important criteria have been added (e.g. the criterion 'Ability to steer development dialogue, manage investment flows and transparency') as they were still absent in current discussions, or made more ambitious than recommended by other publications (e.g. 'Energy partnerships and coordination with regional efforts', based on (Bundesregierung, 2020). Other criteria have been combined and extended to mainstream the 'additionality principle'. The overarching criteria groups are aligned with the overarching dimensions of sustainability:

(1) Social,

(2) Ecological,

(3) Economic and

(4) Political.

The proposed set of criteria thus highlights fairness aspects much more than previous recommendations for producing/importing green hydrogen. Ultimately, they are supposed to support countries of the Global South in demanding fair conditions. Table 8 provides an overview of the individual criteria for the four dimensions, which are then explained and defined in more detail.

The discussion has demonstrated that on the one hand, there is a need to brace against the risks of ecological, social or economic imbalances through large scale infrastructure projects. On the other, the postulate of 'Additionality 2.0' has demonstrated that there are significant opportunities to design the projects in such a way that the contribute actively to local development. Table 8 illustrates how these two approaches can be captured in different ways for the same basic set of criteria.

Table 8: Criteria for 'Fair Green Hydrogen'

| Dimension | Criteria | Necessary safeguards | Additionality 2.0 |
|---|---|---|---|
| **Social** | Contribution to the social SDGs | Is domestic progress towards the SDGs protected? | Is there a positive contribution to the SDGs? |
| | Respecting and promoting of human rights | Are the standards in the area of human rights respected? | --- |
| **Ecological** | Land use and exclusion criteria | Are land use aspects considered according to international safeguard standards? | Are additional benefits with respect to sustainable utilization of land or land rights provided? |
| | Desalination plants and water demand | Are water requirements covered in a sustainable manner? | Do the hydrogen project create additional water infrastructure and desalination capacities? |
| | Use of carbon dioxide (for PtL) only from sustainable sources | For PtL, is only $CO_2$ from sustainable sources used? | --- |

| | | | |
|---|---|---|---|
| **Economic** | Expansion of renewable energies | Will hydrogen production and the upstream and downstream processes be run entirely from renewable electricity? | Do the hydrogen project create additional energy infrastructure and renewable electricity capacity? |
| | Access to economic opportunities and local value creation | Does the process use local labor, local content and production as often as possible? | Are additional infrastructures being created that will provide additional economic opportunities and local value creation? |
| | Sustainable Financing | Does the funding comply with EU requirements for sustainable funding? | --- |
| | No cross-financing of fossil structures | Is cross-financing of fossil structures prevented? | Are revenues utilized for sustainable purposes? |
| **Political** | Adhering to the principles of good governance | Are the principles of good governance adhered to? | --- |
| | Prioritizing national decarbonization plans / Are national decarbonization plans prioritized? | Do the hydrogen plans have a negative impact ( delay or decrease) on the decarbonization plans? | Do hydrogen plans help increase ambition in decarbonization plans? |
| | Building on abilities to steer development dialogue, manage investment flows and transparency | Are there sufficient abilities, incentives and motivation to steer development dialogue, manage investment flows and transparency? | --- |
| | Introducing and implementation of safeguards | Are safeguards introduced and implemented? | --- |
| | Establishing grievance mechanisms | Have grievance mechanisms been established and guaranteed? | --- |

Source: Own illustration.

### 8.3.1 Social Dimension

The criteria in the social dimension should ensure that green hydrogen production is socially sustainable. The inclusion and consideration of the affected population groups and actors is to be ensured at all levels. This is necessary so that the hydrogen projects are not only considered from an economic perspective but also from a social and cultural perspective and the foreseeable enormous structure-building and transforming effects on existing social, economic, and political structures are reflected.

#### Contribution to the SDGs

The establishment of a hydrogen production must contribute to the sustainable goals (SDGs) at the local and regional level that goes beyond any economic benefits (e.g., taxes). This should include, for example, education or the empowerment of local communities.

#### Respect for and promotion of human rights

Human rights and ongoing processes in the field of environmental and social governance should be starting points for hydrogen projects in countries of the Global South. Among others, this includes the Organization for Economic Cooperation and Development's (OECD) Due Diligence Guidance for Responsible Business Conduct, the United Nations (UN) Global Compact, the UN Guiding Principles on Business and Human Rights, the German Supply Chain Due Diligence Act (LkSG) and the World Bank's Environmental and Social Framework. Further, upcoming and new laws such as the European Supply Chain Law must be considered in the project phase and followed as soon as they enter into force. Annual reports of the implementing project partners have to adequately report on them.

### 8.3.2 Ecological dimension

The ecological dimension ensures that hydrogen production is not implemented at the expense of local or regional ecological structures and resources. This is to prevent extractivist practices and structures and, for example, a hidden export of possibly scare water reserves from the Global South to the Global North. Three criteria can be differentiated.

#### Land use and exclusion criteria

People- and population-centric planning should be the guiding principle for planning any hydrogen or renewable energy project, considering locally different social and environmental circumstances. No parts of the hydrogen value chain (including the generation of renewable-based electricity) should be developed in (ecological) protected areas or land with contested (informal) land rights. No land should be converted that could be used for agricultural purposes in order to avoid land conflicts. Hydrogen and renewable energy infrastructure should only be built where detailed ex-ante assessments do not find any foreseeable threats for the local ecosystem, including water scarcity and other threats multiplied by climate change. Biomass that is no by-product of the agricultural sector or food industry should not be considered as 'green' or even 'renewable' energy source and thus qualifying to produce 'green' hydrogen.

#### Desalination plants and water demand

As desalination plants are inevitable for providing drinking water necessary for producing green hydrogen (at least as long as the electrolysis of salt water is not yet a scalable technical option), they should first and foremost benefit local communities. That is, pre-existing desalination plants should not be re-purposed for producing green hydrogen instead of providing drinking water to people, for agricultural purposes or pre-existing industries. Where desalination plants have to be newly built, their capacity should be high enough to cover the needs of all the different interest groups first before providing water for electrolysis and be powered by renewable energies ('+X-solution'). Moreover, it has to be ensured that desalination plants are constructed and run in a way that has no harmful effects on the environment or people living in its area, including the pouring of brine into water bodies.

#### Use of carbon dioxide (for PtL) only from sustainable sources

For PtL, only carbon dioxide from sustainable sources should be used. Closed carbon cycles can be established and used for this purpose. Also conceivable are processes that extract carbon from the air, either directly through direct air capture (DAC) or indirectly through the use of biomass (plants). The processes used in the process of procuring the carbon must be operated with renewable electricity.

### 8.3.3 Economic dimension

Thirdly, in the context of economic issues, it should be ensured that the production of hydrogen and its whole value chain are not isolated solutions detached from the local or national context but have a sustainable and lasting impact and added value for the local and national economic, research and industrial landscape. Where these benefits are not yet sufficiently present, the establishment of hydrogen production can be their starting point. Here, the transitions to industrial and development policy issues and topics are fluid and should be considered accordingly and answered on all sides across all ministries. Four criteria can be differentiated.

#### Expansion of renewable energies

No existing renewable energy infrastructure should be used for producing green hydrogen deemed for export ('Additionality Principle'). International hydrogen producers should fully cover the costs for installing the required renewable energy electricity production capacity and maintenance of the same.

As countries of the Global North (e.g., Germany) have been historically responsible for causing the climate crisis, and still lack ambitions for holding global warming to less than 1.5°C, these very same countries should additionally support hydrogen partner countries of the Global South in upscaling their renewable energy capacity within the framework of

‘Additionality 2.0’. This means installing and financing not only the renewable energy capacity needed for hydrogen production, but additional capacity that will then benefit the local population and economy.

### Access to economic opportunities and local value creation

Wherever possible local workforce, local content and production should be used. Instead of hoping for a ‘trickle-down’ of wealth generated by hydrogen projects, along the value chain economic opportunities should be ensured for the local workforce of the hydrogen exporting country, across different levels of education, age, gender and (dis)ability. Additional infrastructure, business models and adequate training (practical and academic) of local communities for emerging jobs should be provided by local and international project partners, both in the renewable energy sector as well as hydrogen sector and along the entire value chain of hydrogen and its potential downstream products (e.g., ammonia and fertilizer production) or uses.

### Sustainable Financing

The large amounts of investment required for hydrogen production and transport infrastructure can only be provided by private and public capital. Long-term commitment of governments and guidance on sustainable financing are necessary to generate the necessary private capital. For guidance on sustainable financing the corresponding EU taxonomy for sustainable activities must not be used as it is misleading.

At the same time, it should be prevented that the debt burden of many countries of the Global South rises even more. Government funds from the exporting countries should not be used to incentivize the private sector’s location decisions for export facilities. Private operators of hydrogen production facilities or infrastructure should pay taxes locally. If governments from import-minded countries would like to help, they can do this in the form of non-refundable loans only, as long as no perverse incentives to counteract any of the other criteria for fair and green hydrogen are counteracted.

### No cross-financing of fossil structures

The revenues generated from the production and possible export of hydrogen must not be used for the maintenance or expansion of fossil structures and thus indirectly cause ecological damage. The profits should be used in the sense of an ecological transformation in other areas so that the country can achieve its decarbonization goals and implement sustainable adaptation and mitigation measures.

#### 8.3.4 Political dimension

The global demand for hydrogen has an overwhelming potential for transformation in both importing and exporting countries, which should be moderated by political frameworks. The political dimension should determine the limits and scope of action of these transformative processes and thus steer technical, economic, and social developments in the desired direction.[83] Five criteria can be singled out.

**Adhering to the principles of good governance**

Good governance has the following characteristics, among others:

- Transparency and effectiveness
- Accountability
- Inclusion of all people
- Consideration of minorities and the needs of the vulnerable.

A holistic political perspective should be guiding the investment process, which takes into account that infrastructure investments, like those in green hydrogen and renewable energy infrastructure, are not solely a means of economic or energy policy, but equally of industrial, climate or development policy. Thus, all the relevant ministries of the exporting country should have a say in negotiating hydrogen partnerships.

Standards for participatory planning on the level of the individual projects have been tested in diverse contexts and should be applied. Annual reporting from regulators and operators of hydrogen infrastructure, including on financial, labor, environmental and any contested issues, should be required and include information on investment flows and benefits to local communities and the respective region(s) more generally.

**Prioritizing national decarbonization plans and hydrogen strategies**

In the sense of the additionality principles, NDCs and national climate protection plans of the implementing countries should be considered the baseline for the emissions trajectory and local hydrogen needs. Green hydrogen projects deemed for export should not curtail these national ambitions, particularly in the light of lagging industrialization of many countries of the Global South, and that producing (green) hydrogen is much more energy intense than using renewably energies straightaway. But they might contribute to the domestic energy consumption, with the intent of decarbonizing it.

As a rule, national decarbonization ambitions should be prioritized, and thus only surplus renewable energy used for producing and exporting green hydrogen.

[83] For further details see Weischer et al. (2021).

### Building on abilities to steer development dialogue, manage investment flows and transparency

Partner countries must have the ability, incentives and motivation and must be in a position to plan and steer such large and comprehensive infrastructural. This requires that the relevant actors at national, regional, and local level have the necessary capacities and knowledge. In case of doubt, the relevant bodies and institutions should be enabled through capacity building to engage constructively and participate effectively in decision-making.

### Introducing and implementation of safeguards

Strategic impact assessments as well as environmental impact assessments and life cycle assessments (including adequate recycling solutions) should be necessary and guiding tools for building and scaling up local hydrogen economies in a sustainable way.

The introduction or implementation of occupational health and safety regulations, labor laws and trade union organizing rights should also be ensured accordingly.

### Establishing of grievance mechanisms

Non-judicial grievance mechanisms against all private actors involved in hydrogen projects and reporting requirements for the same should be installed. At both the local and regional level stakeholders (affected population, NGOs, civil society, etc.), should be consulted and involved during the whole project planning and implementation process. Only with the ‘social license’ to operate as well as perceived and experienced local benefits should these plants be allowed to run. Litigation options before courts need to be available, as well.

# 9 Requirements for the implementation

The national and international policy dimensions of the reasoning in this study is summarized in the following along four themes: Infrastructure building, energy capacity building, financing, institution building. These themes structure the multifaceted issues, but they are also interwoven, so they cannot be considered in isolation.

In the following, the requirements for the implementation of the set of criteria elaborated in chapter 8.3 will be discussed from a German perspective. In this way, their connection to a concrete political practice as well as their implications for future policy and investment will be made clearer.

The catalogue of criteria can be implemented successively while operationalizing and testing individual criteria. It would be helpful to disseminate them widely including in the NGO community, but also with Development and Planning Ministries of Southern and Northern countries. They could be standard items considered in MoUs and agreements that govern

Hydrogen and Energy Partnerships, which can bring them to life. It will be important to help shape the corresponding developments from the beginning and to align any structures and path dependencies as well as possible with the criteria for fair green hydrogen. It will also be important to document the experiences and feed these experiences back into an improvement of the criteria.

In principle, the development of hydrogen production and then the (partial) export of green and fair hydrogen offers significant opportunities for gradually transforming fossil-exporting countries or otherwise extractivist structures into sustainable economies. The transfer of competence in the field of renewable energies and sustainable water management and treatment that goes hand in hand with the production of green hydrogen can be a stimulus for other economic sectors. The criteria outlined in this study, which also focus in particular on the fairness component, can lay the foundation for a change in awareness among all actors involved and thus become an advantage for the local populations and value chains.

## 9.1 Infrastructure building

The production and transport of green hydrogen is infrastructurally challenging. At least three factors must be taken into account: renewable energy potential, water availability and transport connections. The case studies have shown that a trade-off between these three variables is often necessary, as the perfect site for the large-scale production of hydrogen is often unavailable. Assuming, energy and water are easier to transport over long distances to the hydrogen production site, so the decisive point would be ultimately the logistics of transporting the hydrogen to the export facility. The production of hydrogen near the coast seems generally preferred, as both energy (e.g., through offshore wind power) and sufficient water resources (through desalination plants) would be available there. Coastal states thus seem to be at an advantage, but here too there are major challenges (coastal protection, brine management, etc.) to be considered before the production of hydrogen is truly green and fair, in compliance with all necessary criteria and standards, and profitable.

Countries without a direct connection to the sea have to overcome greater infrastructural challenges with regard to the transport of hydrogen. In principle, pipelines are available as a technical solution, but this is also correspondingly cost-intensive and in most cases requires transnational coordination. These infrastructures may also have to be secured over long distances (e.g., against terrorist attacks, etc.). For West Africa, an above-ground pipeline might be a solution, similar to the existing or planned gas pipeline systems (e.g., TransMed pipeline or the long-planned or not yet implemented Trans-Saharan Gas pipeline from Nigeria via Niger to Algeria). However, it should be noted that blending hydrogen with natural gas – while technically possible – is not preferred. Existing pipelines would have to be converted to hydrogen from natural gas would first have to be developed or made ready for the market.

The infrastructural "bridge-building" to Africa is likely to be largely financed from Europe. In addition to the cost aspect, geopolitical and developmental considerations must also be taken into account when planning the infrastructure. In parallel, the national prerequisites described above can be created – also with help from Europe – which will ultimately enable participation in the global hydrogen economy and open up new development opportunities for the currently less developed countries (such as Niger). From a German perspective, while the German aid agencies can be actively involved and driving some of these processes, it will be beneficial to approach the challenge in very close coordination with the European Union and its other Member States, to avoid unfortunate competitive situations, and ensure that the criteria for Fair and Green Hydrogen are observed by as many stakeholders as possible.

Since the development of the corresponding infrastructure is complex, cost-intensive and takes a long time (both in Africa and on the importing side in Germany and Europe) and corresponding path dependencies will arise here, it is advisable that the infrastructure is not designed for 'dual-use', i.e. that the supplier countries do not focus on fossil exports and hydrogen at the same time, but that the infrastructure development in question is clearly focused on hydrogen. Unlike in the European or Eastern European context (in interaction with Russia), in the African context there is little recourse to already existing infrastructure (which still needs to be adapted to hydrogen). This opens up the opportunity to find new useful and optimal solutions for logistics in cooperation with the African partner countries without already existing restrictions.

## 9.2 Energy capacity building

There is great technical renewable energy potential in all West African countries. The continuous and trouble-free availability of energy is important for hydrogen production, which is why corresponding battery or storage systems must be planned when using wind and solar power. Drawing the power from the existing power grid could mitigate this necessity. But in this case, the grid's condition, connection to the grid and the existing electricity mix must be taken into account. In the case studies on Senegal and Niger, it became clear that these countries still have very low RE quotas in their electricity mix. This ratio of fossil to renewable electricity would first have to be changed through the addition of RE resources and the necessary adjustments to the electricity grid before green hydrogen production would be possible. Ambitious political strategies for the expansion of renewable energies and the electricity grid are needed here. However, such an expansion must take place on a massive scale and would take considerable time. If one were to wait until the conversion and the necessary adjustments in the respective national electricity mixes were completed before setting up hydrogen production, the time of hydrogen production might be far later than the global (and for Germany) demand for green hydrogen.

In all of this, the additionality principle 2.0 should be the guiding principle. One solution could be the parallel development and expansion of both the energy system and hydrogen production. In this case, hydrogen production is conceived as an isolated solution, i.e., the necessary energy infrastructure required for hydrogen production is aligned with hydrogen production and built up accordingly. In order to meet the fairness criterion, however, such isolated solutions must always make additional capacities of renewable energy available to the domestic electricity market and thus successively advance its modernization and orientation towards renewable energy. Building and financing of these capacities – which would be additional to the needs of the hydrogen production – need to be agreed between investors and the country and quantified with respect the contribution to national sustainable development, again under inclusion of affected populations and environmental NGOs.

Depending on demand, these additional capacities could be implemented in different shapes: with direct input into the (if existing) existing national or regional electricity grid or as an indirect variant through the development of decentralized structures and production (agaportal, 2022). Here, it is important that the partner countries or project actors involved (business enterprises, etc.) as well as civil society actors jointly find country-specific solutions and then implement them adapted to the respective circumstances.

In any case, the energy supply of the respective country must be advanced in such a way that the economic development of the partner countries makes such progress that they not only export the hydrogen produced but can also process it locally in their own value chains and use it appropriately. For this reason, the exchange of know-how in the relevant fields should be an integral part of every hydrogen partnership. The establishment of hydrogen production and the associated expansion of renewable energies can be a door opener for this and open up corresponding sustainable business fields and development opportunities.

This means that there are lots of preconditions for hydrogen exports from countries like Niger and Senegal, begging the question whether these demands are realistic. Can they be used by investors or other stakeholders to open doors, without any serious intention of complying to these criteria? Partial fulfillment might be as dangerous as ignoring the criteria. The proposal is to discuss all these criteria further in a conversation between science, the politics and NGOs.

## 9.3 Financing

Building up the infrastructure is expensive. Most likely, significant private investment will be included, specifically in the production facilities. But depending on the situation, governments or public utilities might also be involved. They have very different access to investment capital as well as to donor support. Several options are available for Germany level for financing hydrogen projects abroad.

The first option to be mentioned is the German funding program for international hydrogen projects within the framework of the National Hydrogen Strategy and the Economic Recovery Plan (BMWK, 2021). It is explicitly geared towards projects for the production of green hydrogen. A total of EUR 350 million in funding is available for the period until the end of 2024.

The funding guideline points in the right direction with regard to the criteria (e.g., presentation of renewable electricity procurement; sustainability of water procurement; waste and pollutant management; social and environmental compatibility; ILO-International Labour Standards to be fulfilled for funding), but its volume and time limitation are currently too limited for steering investments and projects on the necessary scale. If the market and thus the demand develops as expected, economic actors will also become active outside of the funding guideline and thus outside of the criteria framework required in the guideline.

One option specifically for the private sector investors, are Export Credit Guarantees, In Germany called Hermes Cover. They are a government instrument covering policy risks for private investors, thus enabling investments in contexts in which economic actors' risk perception would be prohibitive. When awarding these Hermes Covers, projects should usually also be assessed for compliance with environmental and social standards and respect for human rights (BMWK, 2022a). Export transactions that violate internationally defined environmental, social and human rights standards would not be covered. When examining these aspects, the World Bank Operational Safeguard Policies, the Performance Standards of the International Finance Corporation (IFC) and the Environmental, Health and Safety Guidelines of the World Bank Group are relevant in accordance with the OECD rules and regulations.

Other options are KfW's own Deutsche Investitions- und Entwicklungsgesellschaft (DEG), for the private sector which offers project finance for projects in emerging economies. These are mostly limited to countries on the OECD DAC list. Finally, GLS Bank offers loans in the areas of wind energy, photovoltaics, biomass and hydropower. Currently, the bank can provide up to EUR 20 million in debt capital per client, higher amounts only with the involvement of a syndicate partner or trustee.

Indirect financing of hydrogen production projects is possible through the innovative funding instrument H2Global. For this instrument, EUR 900 million were approved by the German Federal Ministry for Economic Affairs and Climate Protection at the end of 2021. The approach of this instrument is that, in line with the sustainability criteria, green hydrogen or its derivatives are purchased via an intermediary at the corresponding currently high price and then sold at a lower market price (in competition with other types of hydrogen) and the price differential is compensated by subsidies from the federal government. "H2Global is therefore a funding construct with which the price difference between green and grey hydrogen is to be balanced out, in order to create a supply of green hydrogen on the one hand and to integrate green hydrogen into application processes in a timely manner to reduce emissions on the other. One premise of H2Global is that no functioning market for green hydrogen exists at the current time, as potential supply and actual demand prices are too far apart." (H2international, 2021)

It would be worth considering applying this approach to individual countries or groups of countries (e.g., West Africa) in order to stimulate the development of hydrogen production in a focused manner.

## 9.4 Institution building

Most importantly, the criteria for fair green hydrogen must be legally anchored and implemented both in Germany and Europe and in the partner country. The discussions and findings must be fed into the corresponding political processes in order to create planning and action security for all actors involved. On the German side, initial approaches in this regard can be found, for example, in the funding guideline for international hydrogen projects or in the Act on Corporate Due Diligence in Supply Chains, but decisive criteria are not sufficiently formulated.

In the case of the Act on Corporate Due Diligence in Supply Chains, it remains to be seen which of the promising regulations will ultimately be implemented in concrete terms and defined by case laws. It must also be taken into account here that the law only applies to companies above a certain size (from 2023 companies with more than 3,000 employees; from 2024 companies with more than 1,000 employees) and thus potentially does not cover the entire value chain and all actors involved. Here, further developments at the European level must also be kept in view.

It has become clear in the case studies that the prerequisites necessary for the comprehensive production and export of fair green hydrogen are not yet in place. In order to remedy this, capacities still need to be built up in a wide range of areas, starting with the area of research and training of skilled workers. There are initial approaches here (e.g. the graduate school in cooperation with WASCAL (FONA, 2021)), but they are not sufficient to cover the foreseeable demand. It would also be conceivable to have broad-based exchange programs in the relevant disciplines/subjects (e.g., along the lines of the Erasmus programme). Since such programs have correspondingly long lead times, they should be started as soon as possible.

Action requires awareness, which is why it is advisable to firmly anchor the hydrogen issue on the agenda in the exchange with West African countries and thus to raise awareness among potential partners for the potential of hydrogen partnerships and to introduce the possibilities and advantages of the production of green and fair hydrogen in the political and public discourse. The involvement of local NGOs can also be helpful here. NGOs could, for example, demand more ambitious decarbonization plans from their governments or make the option of producing fair green hydrogen for their transformation to climate neutrality more prominent in the respective national discourse. When confronted with hydrogen projects, in planning or implementation stage, they can work in transnational cooperation with other (German) NGOs to advocate for compliance with and implementation of the Fair Green

Hydrogen criteria and pursue any violations legally in their countries or in Germany. Appropriate capacity building at the civil society level is important here.

In order to avoid neo-colonial structures in the hydrogen economy, the processes and discussions in the Hydrogen Partnerships should be as inclusive as possible. This means that political and civil society representatives of the respective regions and NGOs should also be involved in the planning of possible locations. Likewise, all actors involved should go beyond the current legally stipulated requirements and criteria and agree on more comprehensive criteria that guarantee the production of genuine green and fair hydrogen. Ideally, these criteria should be anchored at the European or international level in order to prevent a race-to-the-bottom in this future-relevant and highly competitive field.

## 9.5 Further thoughts

It should be noted that it can be assumed that the enormous demand for green hydrogen, the long lead and build-up times and the highly dynamic technical developments will lead to an increase in the need for action in the future, but also in the scope for action, which will then have to be filled politically. There is a danger that in such dynamic developments the time for developing standards will be lost and much will be subordinated to the achievement of goals. Therefore, it makes sense to formulate criteria for the production of green and fair hydrogen as early as possible, so that processes and structures can already be aligned accordingly in the initial phase that is now beginning. The resulting path dependencies and guard rails thus guide future action and enable the criteria that may be challenging in the short term to become effective in the medium term and thus the medium- and long-term benefits to become visible for all actors involved. From this, a role model effect and a standard can be established that can prevent the emergence of neo-colonial structures in other contexts as well.

However, considerations and approaches for more efficiency and sufficiency must also be taken into account, which at least critically question the prevailing growth model, neither through own production of green hydrogen in Germany or Europe nor through the currently non-existent production structures in the Global South.

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