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Technical, economic and social analyses of the development of a sustainable global hydrogen atlas.

HYPAT Working Paper 06/2023

Interdependencies between national energy transitions and international hydrogen cooperation

Authors:

Doris Vespermann, Dr. Sascha Thielmann (GIZ)

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Project Lead

Prof. Dr. Martin Wietschel
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Str. 48, 76139 Karlsruhe, Germany
martin.wietschel@isi.fraunhofer.de

Project Website

https://hypat.de/hypat-en/

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1 Introduction and Objective

Green hydrogen is considered an essential component to achieve global climate targets and the decarbonization of all sectors. International hydrogen demand is set to increase significantly in the future according to a large number of studies[1]. This is already apparent today in the fact that the topic of hydrogen is firmly anchored in numerous energy and hydrogen partnerships between potential importing and exporting countries.

Due to their high potential for green hydrogen production, many emerging and developing countries are also considered promising future trade partners. With the perspective of a newly emerging market, numerous international hydrogen cooperation projects have been formed in recent years between industrialized nations and countries of the Global South (World Energy Council, 2020). From the viewpoint of the importing countries, the goal of such cooperation is to support the ramp-up of the hydrogen market in the partner countries and to establish stable hydrogen supply chains with the associated security of supply at home.

Germany is one the countries that will not be able to meet its own projected demand for green hydrogen by itself. This is why the German government is also putting emphasis on imports from countries of the Global South in its updated National Hydrogen Strategy (Bundesregierung, 2023). Germany has set itself the goal that imports must be based on sustainability criteria that still have to be defined in an import strategy. Key aspects of this were already stipulated in the National Hydrogen Strategy of 2020 (Bundesregierung, 2020). Among other things, this includes the premise that local markets and a local energy transition in the partner countries should not be hindered but supported by the production of green hydrogen.

However, the upcoming ramping-up of a global hydrogen economy means it is conceivable that a local energy transition could be hindered by a producer country developing an export-oriented hydrogen economy. As a result, the greenhouse gas reductions achieved by producing and using green hydrogen could be lower than anticipated when viewed globally. To be able to identify such effects, it is necessary to analyze the possible interdependencies between national energy transitions and the development of an (at least partially) export-oriented hydrogen economy (in the following referred to as "international hydrogen cooperation"). Only then is it possible to consider these effects in the further design of hydrogen cooperation and, for example, incorporate them into political or regulatory framework conditions. From a broader development policy perspective, the energy transition does not just involve turning away from fossil energy sources, but also achieving universal access to clean energy for the population in the producing countries.

Against this background, the objective of this Working Paper is to compile the important correlations between national energy transitions and international hydrogen cooperation. In particular, this concerns identifying opportunities and synergies as well as potential risks and conflicts of hydrogen projects in selected partner countries of the Global South. The focus is on specific interdependencies such as the impacts on achieving national energy transition and climate goals, on expanding renewable energy sources to supply electricity locally, on energy

[1] see, e.g., (Joint Research Centre, 2019), (Quarton, et al., 2020), (Wietschel, et al., 2021), (World Energy Council, 2021), (Riemer, et al., 2022), (Fraunhofer ISI, 2022).

infrastructure or on the availability of skilled workers. Both political and technical aspects are considered.

In addition to supporting local energy transitions, other sustainability aspects such as environmental impacts or local participation play an important role in the establishment of sustainable international hydrogen supply chains that also make sense in terms of climate policy. This Working Paper focuses mainly on the impacts of international hydrogen cooperation on local energy transitions. However, looking at this in isolation is neither possible nor sensible, as the national targets of a local energy transition are closely interwoven with the socio-economic interests of the partner countries. The goal of this Working Paper is therefore to identify points of connection through which conflicting interests can be avoided and local energy transitions supported in line with the sustainable development goals of the United Nations Agenda 2030.

2 Methodological approach

To analyze the impacts of international hydrogen cooperation on local energy systems and ultimately local energy transitions in potential hydrogen-exporting countries, the relevant publications were reviewed, and interviews conducted with local experts from eight potential producing countries. The research and interviews were structured using a guideline encompassing qualitative and quantitative indicators. In this analysis, the term energy transition stands for both turning away from fossil energy sources as well as achieving universal access to clean energy. The focus of the guideline is on specific interdependencies, for example regarding impacts on the expansion of renewable energies, existing energy infrastructure, competition for public commodities or raising public awareness. Specifically, the guideline contains questions on (i) national objectives of a local energy transition, (ii) the role of hydrogen in a national energy transition, and (iii) targeted synergies and potential risks for conflicts of interests of international hydrogen cooperation when implementing local energy transitions.

i. National objectives of a local energy transition

This part of the guideline aimed at assessing potential hydrogen exporters' level of ambition with regard to an energy transition at home. Data on the country's existing energy system were collected to do so, including the share of renewables in electricity demand and primary energy demand, the rate of electrification, and the country's goals with regard to achieving greenhouse gas neutrality and universal energy access. In particular, this also involved reviewing documents such as national energy transition or electrification strategies. In addition, within the interviews, assessments were obtained of the national energy planning process or the status of achieving the national energy transition strategy in order to estimate how actively the energy transition is pursued and how important it is for national policy.

ii. Hydrogen's role in a national energy transition

The content or the planned objectives of a national hydrogen strategy or roadmap should provide information about which changes to the energy system of partner countries are being targeted and considered due to hydrogen activities in the country. Here, particular attention was paid to the hydrogen strategy's set goals for decarbonization. Both national demand and the willingness to pay for green hydrogen and its derivatives in individual sectors as well as export plans were considered. For export projects, in particular, it was questioned what contribution these can and explicitly should make to the local energy transition.

Furthermore, this section also asked which national standards should apply to the production of green hydrogen and how internationally planned standards are regarded in the country. In this context, it is particularly interesting to find out the local perspective and assessment of the European Union's planned requirements (European Commission, 2023), which aim to ensure that importing certified, green hydrogen does not directly or indirectly lead to cementing fossil infrastructures in the producing countries. This is to be done through criteria such as the additionality of renewable energies for hydrogen production and the temporal and spatial coupling of electricity generation and hydrogen production, among other things. Whether and how these requirements are complied with and interpreted is therefore of relevance for this Working Paper.

It is also examined to what extent the hydrogen strategy's goals and expansion plans are compatible with the country's energy transition strategy. Additionally, there are questions about how hydrogen is considered in national energy planning.

iii. Targeted synergies and potential risks of conflicts of interest of international hydrogen cooperation when implementing local energy transitions

In addition to the research on existing and planned hydrogen cooperation and its orientation, this part explicitly addresses the expected synergy effects and possible conflicts with regard to the implementation of a national energy transition and the corresponding need for international support. The central question was to what extent targeted synergy effects can be realized and facilitated or potential risks be avoided by appropriate regulation. This should address both quantitative effects (for example, the influence on expanding renewable energies for local use or the grid) and qualitative effects (such as raising general awareness of the energy transition or the country's international visibility as a pioneer of green technology).

For a first estimation, using the guideline's questions, a literature search was made of the relevant information contained in official documents, strategies and scientific studies of the eight analyzed partner countries of the Global South (Brazil, Chile, India, Kenya, Morocco, Namibia, South Africa and Tunisia). Subsequently, the same questions were verified and discussed in interviews with one to three local experts in each of these partner countries. The interview partners were selected based on their expertise in designing and developing the local energy system and are all familiar with the political, technological, socio-economic and ecological issues associated with entering a global and local hydrogen economy. Although these conversations with individual local experts are not representative and only offer an initial subjective impression, this change of perspective often allows further insights into the possible effects of international cooperation, which can then be underpinned by data from the literature. Based on the research and the results of the standardized interviews in the analyzed countries, important interdependencies of international hydrogen cooperation and local energy transitions were identified as well as pointers for international collaboration. These are presented in Chapter 3. More detailed information on the respective country contexts can be found in Chapter 4.

3 Key interdependencies between national energy transitions and international hydrogen cooperation

The global interest in green hydrogen is being accorded high political attention in the eight regarded potential partner countries Brazil, Chile, India, Kenya, Morocco, Namibia, South Africa and Tunisia. The emergence of a global market for green hydrogen is primarily regarded as an opportunity for socio-economic development. There are hopes of newly emerging industries, infrastructure, jobs and revenues that promise economic upturn and growing prosperity. In many of the countries considered, energy demand is expected to multiply in the next decades, not only due to entering an export-oriented hydrogen economy, and some of this demand can be met hydrogen. The positive climate impact of green hydrogen and the related contribution to meeting climate targets in various sectors are important arguments for getting involved in a green hydrogen economy. For industrialized nations, using green hydrogen is already considered the missing piece of the puzzle to decarbonize processes in sectors with previously no decarbonization options, for example in the chemical industry, steel production or aviation and shipping.

However, it is precisely this climate impact and the actual contribution of hydrogen to local energy transitions that are often not examined from multiple perspectives. If there are insufficient or non-existent standards or regulations, the production and use of green hydrogen and its derivatives can also have negative impacts on the local energy system.

In principle, the risks posed by global warming, the urgency of effective climate protection and the necessity for energy transition are recognized in all eight countries. Therefore, there is a prevailing hope in all the analyzed countries that they will be able to realize many of the opportunities of an emerging green hydrogen market for the local energy transition; interview partners often spoke about a unique window of opportunity or a win-win situation. The awareness of possible negative impacts or missing synergy effects for the local energy system, on the other hand, varies widely in the different countries. This is largely due to the particularities of local energy systems and the respective focus of the national hydrogen strategies.

To be able to realize the opportunities, it is necessary to know the potential risks, take these into account when planning strategy and have measures in place that mitigate or avoid these risks. International partnerships can provide support here under certain circumstances. Chapters 3.1 and 3.2 therefore specify the possible opportunities and risks of international hydrogen cooperation projects for local energy transitions that have become apparent in several or all of the analyzed countries. These have been clustered along the hydrogen value chain into the blocks of capacities and training, electricity generation, infrastructure and hydrogen use. For additional clarity, they are also listed as bullet points in Table 1 in chapter 3.3.

3.1 Opportunities of international hydrogen cooperation for the implementation of local energy transitions

- **Capacities and training**

The high public interest in hydrogen can lead to greater general awareness of the energy transition and especially the expansion of renewable energies. Skilled workers have to be trained or retrained to meet the needs in the hydrogen sector. These skilled workers are then not only available to the hydrogen industry in a narrower sense, but can also become an important basis, for example, for the continued expansion of renewable energies for the local energy transition, since their knowledge and skills can be used more broadly. The demand for appropriate training programs may rise and reach a critical mass, at which it becomes economically viable to develop training programs on a larger scale, but also to develop local renewable energy companies more extensively. Getting involved in a green hydrogen economy can therefore support scale effects in capacities and training, although these are more likely to occur in the medium term. Many international cooperation projects are willing to train skilled workers and create local know-how. To do so, cooperation often takes place with local universities and research institutions that can develop new knowledge in the process and expertise adapted to the specific country contexts, which is also relevant for other specialist areas of the energy transition.

- **Electricity generation**

There is great hope with regard to hydrogen projects and the implementation of local energy transitions that these will be accompanied by the accelerated expansion of renewable energies to supply power locally. This can be indirectly supported by the above-described scale effects if the skilled workers required are trained on a larger scale. It is also partially expected that hydrogen projects will attract investors who will then also invest in renewable energies for local energy supply. In connection with hydrogen projects, there is often a discussion of oversizing PV and wind power installations so that the "surplus" amounts of renewable power can be made available for local use.

Especially in countries pursuing the goal of exporting large quantities of hydrogen, there will be a huge demand for renewable power generation components, such as PV modules. Many of the countries studied are following the approach of using local manufacturing to meet at least some of this demand in order to bring about increased local value creation. Depending on the local conditions, the plan is to manufacture simple components locally (such as cables, PV assembly systems, towers for wind turbines) or technically more complex components (e.g., PV modules, rotor blades). In any case, increased demand for such components from entering the hydrogen economy creates a local sales market, which can make local manufacturing more attractive and economical. If local manufacturing can be established in the field of renewable energy technologies, supply chains may become simpler for projects of local use and may foster the local expansion of renewable energies.

- **Infrastructure**

Most countries are also reckoning with synergy effects for the local energy system for the expansion of grid infrastructure and the improvement of the security of supply. As water is required for electrolysis on the one hand and, on the other hand, ports are considered important export terminals for hydrogen products, hydrogen production will often take place near the coast. The production of the required green electricity will not always be possible in the immediate vicinity. To transport this from the interior of the country to the electrolysis sites, it is necessary to expand the local electricity transmission networks and this should be supported by hydrogen project developers. If the country plans its grid expansion strategically, this can lead to improved grid stability, energy access, and thus greater security of supply. At the same time, the grids can be modernized and new electricity market designs introduced, which create additional incentives for the deployment of renewable energies. In addition, there is the sector-spanning relevance that hydrogen can have for decarbonizing industry, transport, heating and electricity. In many potential hydrogen exporting nations, strategic planning could integrate options for sector coupling into energy plans at an early stage, and future-oriented, efficient infrastructure development could take place.

- **Hydrogen use**

For the potential exporting countries of the Global South, entering a global market for green hydrogen products often brings about local opportunities to utilize hydrogen and therefore new decarbonization options in various sectors. The local use of green hydrogen products can make a contribution to sustainable economic development in the partner countries. In many of the studied countries, the fertilizer industry is regarded as an important industrial sector in this context. Particularly against the backdrop of globally disrupted fertilizer supply chains due to Russia's war on Ukraine, developing integrated projects between industry, agriculture and the population can complement food security with the energy transition (energy-water-food nexus). To what extent a more widespread use of green hydrogen in local industry is likely to occur depends heavily on how the production costs for green hydrogen develop and the willingness to pay possible premium prices for "green products". In the medium term, such demand is seen for export goods that were produced using green hydrogen (e.g., green steel). These exports are expected to generate revenue. This foreign exchange, in turn, can be used to push the expansion of renewable energies, infrastructure development or training programs and thus further advance the energy transition in the country.

3.2 Potential risks of international hydrogen cooperation for the implementation of local energy transitions

- **Capacities and training**

Planning, constructing and operating hydrogen projects require specific specialist knowledge as well as trained workers. In many potential export countries, however, these skilled workers are a scarce resource. High economic interest in hydrogen projects can lead to competition for skilled workers, who are also needed for the expansion of renewable energies for local use. A shortage of skilled workers can significantly slow down the implementation of both hydrogen and renewable energy projects. The same is true for permit issuing procedures. If additional and dedicated administrative resources are not created early enough, there is the risk that hydrogen and renewable energy projects will compete for land use, grid expansion and project permits, and thus slow each other down. Such effects are to be feared, especially in the short term, if the availability of skilled workers and administrative capacities have not yet been adjusted to the new demand.

- **Electricity generation**

If green hydrogen production is to achieve real GHG-savings, additional generation capacities for renewable power must be constructed to operate the electrolyzers. Such electricity generation is usually variable, which poses challenges for operating the electrolyzers economically. To produce hydrogen economically, the aim is to achieve the highest possible utilization of the electrolyzers, since the production of green hydrogen is characterized by high, fixed investment costs, which can be best amortized through continuous operation and high production volumes. However, even at the best locations, only limited full-load hours can be achieved using volatile renewable energies. To ensure that the electrolyzers operate even at times when there is insufficient solar and wind power available, grid electricity from the local power system could be used to produce hydrogen. If this does not involve otherwise unused electricity from renewable energies, this additional electricity will usually come from fossil sources, thus inducing additional CO_2 emissions. This usually applies independently of the electricity mix, because the lowest-cost generation capacity is always fed into the electricity system first. This mostly consists of variable renewable energies like wind and solar. Then, the missing amount of power needed to meet demand is generated using controllable power plants (often fossil-fueled). Even in an electricity mix that uses a high share of renewable energy sources, short-term additional electricity demand is usually met to a large extent or even completely by fossil energy sources. As a result, (even temporarily) operating electrolyzers using grid power from the local electricity system increases the amount of power coming from fossil power plants and therefore increases the CO_2 emissions of the local electricity system. This also applies even if those operating the electrolyzers explicitly buy only "green power" from the grid, because this green electricity is then missing from the grid and has to be "replaced" by other power (usually from fossil power plants). This can reduce or even reverse the climate impact of the hydrogen produced if, in the end, the CO_2 emissions caused by producing the ostensibly green hydrogen are higher than the emissions saved by using it.

This effect can be mitigated if, at other times, surplus green power is fed into the local electricity grid and replaces fossil power generation there. This can occur at times when the renewable power generators built for the electrolysis produce more power than is needed by the electrolyzers. The overall effects are always dependent on the specific electricity systems involved and can only be determined by simulating specific grid and operation setups.

Overall, there is a risk when (temporarily) using grid power that operating electrolyzers will increase the amount of power generation from fossil energy sources in an electricity system. This can also lead to the operation of electrolyzers keeping fossil power plants in the grid for longer or delaying their scheduled shutdowns. In extreme cases, this may even trigger incentives for investing in fossil power plants. All of this could indirectly consolidate fossil power generation structures in the local electricity system and hinder local energy transitions in the producing countries, even though the aim is actually to reduce global emissions of CO_2. This would contradict the requirements of Germany's National Hydrogen Strategy.

Especially in the case of large-volume export projects, there may be additional competition for sites and investments with generating renewable power for the local energy system. Project developers look for the best sites to optimize hydrogen production economically. In addition to other options for using these areas, such as agriculture, nature conservation or residential developments, they are also in competition with renewable energy generation for the local energy system. In some cases, international hydrogen project developers have been able to ensure areas with very high potential for renewable power generation that are then no longer available for the local energy transition. However, especially in those countries whose energy mix is still heavily based on fossil fuels, such land may be better suited to producing very low-cost renewable power for local supply and replacing fossil-based electricity from the grid. In many cases, such direct CO_2 savings would be much more efficient in terms of the abatement costs per ton of CO_2 than the savings that could be realized using hydrogen produced from the same amount of electricity.

Furthermore, the construction of hydrogen production plants and the additional electricity generation capacities is accompanied by high capital requirements. Due to the greater attractiveness of international hydrogen projects (which could have lower risks and higher returns as export-oriented projects with strong international participation), investors may be more likely to invest in such projects than in expanding renewable energies for local energy supply. However, the latter are urgently needed to advance local energy transitions.

- **Infrastructure**

In several of the countries studied, the electricity transmission network is already heavily stressed today and an unstable power supply is commonplace. In many countries, the expansion of renewable energy sources is hindered by bottlenecks in the transmission capacities of the power grids, because there is insufficient grid capacity to connect wind and solar parks to the grid. Such grid bottlenecks can be triggered or made worse by additional renewable energies for hydrogen production, especially if the wind and solar power plants are not located close to the electrolyzers and have to be transmitted via the grid. This can inhibit the further deployment of renewable energies for the local electricity system as well. Additional loads due to electrolysis-based hydrogen production can lead to further overall strain on the existing infrastructure and consequently to grid instability, more frequent load shedding and therefore increased supply insecurity.

Especially in countries that still have large deficits in terms of energy access, electrification and security of supply, it became clear during the discussions with local experts that they are worried these topics could slip down the political agenda due to an overriding focus on hydrogen. While it is often announced that overcapacity will contribute to better electricity supply at home, the challenges associated with the electrification of rural areas are completely different from those of realizing a large-scale project to manufacture hydrogen products. In addition, the electrification required is not necessarily concentrated near potential hydrogen project sites, but is usually widely distributed across remote parts of the country. This would often require a substantial expansion of the local electricity networks (especially at the level of distribution networks). If there is high (political) focus on the economic opportunities of exporting hydrogen, there is the risk that improvements to energy access in remote regions - and therefore the internationally targeted universal access to energy - will be delayed.

- **Hydrogen use**

Although studies in several of the countries show they have potential to use green hydrogen products for local decarbonization, it was very clear from the discussions with local experts that there is currently hardly any willingness locally to pay more for "green" products such as green steel than for conventional products. In this context, therefore, it does not seem very likely that there will be positive effects for the local energy transition from using green products domestically, and that this harbors the risk of investment misallocation or even stranded assets.

Establishing an export-oriented production of green products is also associated with considerable uncertainty due to the currently still unclear international market situation.

3.3 Overview

The interdependencies described in the previous subchapters between international hydrogen cooperation and local energy transitions, which were apparent in some or even in all of the countries analyzed are listed again as bullet points in Table 1. Using thematic clustering, the table provides a direct comparison of the opportunities and risks involved.

Table 1 General opportunities and potential risks of international hydrogen cooperation when implementing a local energy transition

Cluster	Opportunities	Risks
Capacities and training	• Raising awareness for the energy transition and creating additional resources due to high public interest in hydrogen • Training of skilled workers and establishing training programs in the field of renewable energy • Investments in local research institutions	• Slowdown of project implementations due to competition for workers • Slowdown of permit procedures due to competition for administrative resources
Electricity generation	• Accelerating the expansion of renewable energies for local use through scale effects • Increased attractiveness for investors • Additional capacities through oversizing renewable power generation capacity in hydrogen projects • Emergence of local manufacturing of renewable energy components (e.g., PV mounting systems, towers for wind turbines, PV modules)	• Increased operation of fossil power plants if electrolyzers are operated using power from the grid • Slowdown of the replacement of fossil energy in the energy mix; consolidation of fossil energy generation structures • Competition for good locations for wind and solar from export projects • Competition for investment between renewable energy projects to produce power for local use and for hydrogen production
Infrastructure	• Accelerating the expansion of cross-sectoral energy infrastructure • Expanding the electricity transmission network and improving grid stability • Broadening energy access • Modernizing electricity market design and networks • Integrating sector coupling into energy planning	• Competition for existing infrastructure, with power grid congestion/load shedding/supply instabilities • Delays to improving energy access due to the focus on hydrogen production
Hydrogen use	• Emergence of new decarbonization options in different sectors • Export opportunities for green products and reinvestment of revenues in the local energy transition • Development of integrated projects (energy-water-food nexus) between industry, agriculture and population	• “Stranded assets” due to an unwillingness to pay more for green products for local use

4 Detailed information on the specific country contexts

The production and use of green hydrogen products is a global issue. However, the opportunities and challenges connected with the emergence of a global market for green hydrogen products vary greatly depending on the respective local context. The following subchapters give examples from eight countries of the Global South. They show what expectations and hopes are linked to green hydrogen and what concerns the topic raises with regard to the local energy transition. The following examples also demonstrate that not all the risks that entering the green hydrogen market has for implementing the local energy transition have been sufficiently considered in every country.

4.1 Brazil

National objectives of the local energy transition

Brazil's electricity mix is relatively low in CO_2-intensity and universal access to energy is considered to have been achieved (Worldbank, 2023). Renewable energies make up 84.2 % of Brazil's total electricity generation capacity, in particular due to its heavy reliance on hydropower, which accounts for almost two thirds of electricity generation capacity. The CO_2 intensity of Brazil's generation dropped by almost 40 % in the five years up to 2020 (Energy Research Office (EPE), 2021). And yet Brazil's ten-year energy plan shows a mixed outlook. Although this forecasts the installation of 8.4 GW of PV and 24.4 GW of wind power capacities by 2029 and a 48 % share of renewable energies in primary energy demand by 2031, it does not include any goals to reduce the use of coal as a primary energy source and assumes that the share of fossil fuels in electricity supply will remain constant from 2030 (República Federativa do Brasil, 2019). In addition, although Brazil has pledged to achieve greenhouse gas neutrality by 2050, so far it has not yet submitted a long-term strategy to the UNFCCC despite announcements to that effect (Climate Action Tracker, 2023). Alongside these official targets, however, it must be mentioned that energy planning played a subordinate role during the last government legislature in Brazil and has only been assigned higher priority again under the new government.

Hydrogen's role in the national energy transition

Green hydrogen is considered an opportunity that should provide additional impetus to Brazil's ongoing energy transition. Therefore, in July 2021, guidelines for the national hydrogen program were announced in the "Programa Nacional de Hidrogênio (PNH2)" (República Federativa do Brasil, 2021). This includes the following six priorities: reinforce research, development & innovation and the technical bases, capacity building and human capital formation, energy planning, legal and regulatory framework, market development and competitiveness as well as international partnership and cooperation. There has been a Working Group appointed to this since 2023, which is coordinated by Brazil's energy ministry. The PNH2 does not yet feature any specific, sectoral decarbonization targets. However, in several industries, such as agriculture, aviation and mining, interest is high in the options of using green hydrogen for decarbonization measures. Developing a green fertilizer industry seems particularly promising. Brazil's agricultural sector is currently heavily dependent on fertilizer imports from Russia, but is regarded as very capable of innovation due to its financial possibilities. There is also great interest in producing and using synthetic fuels for aviation. For general use in the transport sector, however, ethanol is being backed as a low-emission fuel. In the cement and steel industries, there is currently little interest in the options for using green hydrogen. Industry representatives do agree, however, that change in the long term is inevitable. Therefore, for the foreseeable future, it is more likely that these industries will produce primarily interim products based on green hydrogen, especially for export.

So far, the only concrete export-oriented large-scale project is the expansion of the port of Pecém in northeastern Brazil. The Brazilian government is supporting this with 70 million US dollars. The aim is to export green hydrogen products from here to Europe or the USA that have been manufactured using offshore wind energy. So far, however, Brazil does not yet have a standard for green hydrogen and its derivatives; it seems more likely that Brazil will establish a national standard for so called low-carbon hydrogen. The EU's import criteria are regarded as very strict, which could result in a stronger export orientation toward the USA.

Targeted synergies and potential risks for the local energy transition

It is not considered necessary to develop offshore wind power in order to meet the local demand for energy. Projects like the one in Pecém are therefore not in competition with the expansion targets for renewable energies for local use. Onshore wind also has high potential and there are large areas of land available for renewable energies. The costs of developing this potential are largely known. The investment risks for hydrogen projects, on the other hand, are viewed as unclear, so that there has not been any increased private sector investment interest in hydrogen projects so far compared to renewable energy projects. However, the first larger pilot projects, such as that of EDP in Ceara or of Linde in Bahia, are already under construction or even in operation. The Brazilian government wants to continue to support renewable energies despite the already high expansion rates. In view of the rapid expansion, especially of wind power in northeastern Brazil, more and more environmental associations are calling for stricter environmental and social impact assessments and greater consideration of sustainability aspects in approval and planning procedures. However, after the subordinate role played by energy planning processes in the previous legislature, this will first require the restructuring and strengthening of the administrative processes.

Unless there is a massive boom in the hydrogen industry, local experts do not currently foresee a shortage of skilled personnel in renewable energies. In the past, renewable energy qualification programs were offered within the scope of international development cooperation, and hydrogen has also been added to the curriculum at several universities of applied sciences, so that trained workers should be available for this newly emerging industry in the future. However, there is already a high shortage of skilled workers in the field of digital grid infrastructure, which is expected to worsen due to the rising share of variable energies and large loads such as electrolyzers, including grid-connected hydrogen projects. In talks with local experts, the desire was clearly expressed that Brazil should continue to receive international support in training skilled workers. The need for international advice and support through development cooperation, for example when building and operating a pilot plant, was also expressed with regard to the development of suitable regulations and in particular the demand side of the market ramp-up.

Overall, according to the local experts, economic development will always be prioritized in Brazil, but sustainability is also becoming more important. For instance, Brazil is one of the few countries in the world where it already makes sense to develop a hydrogen market right now in terms of climate impact, due to its existing high share of renewable energies and its huge potential to expand these. Nevertheless, it is considered necessary to flesh out Brazil's hydrogen plans and especially the PNH2 and to integrate these into the country's energy planning. When doing so, it is important to establish links to ecological concerns and other sustainability aspects as well as clear sectoral decarbonization targets.

4.2 Chile

National objectives of the local energy transition

Chile demonstrates to be very ambitious in terms of its energy transition. Chile's energy system, which has been heavily dependent on large-scale hydropower, coal, natural gas and oil up to now, is set to undergo a major transformation in the coming years. To this end, Chile has a plan to phase out coal, which will shut down all coal-fired power plants by 2040 at the latest, 65 % of them as early as 2025. The share of renewable energies in electricity generation, which was around 54 % in 2021 (IRENA, Energy Profile Chile, 2022), is to be increased to 80 % by 2030 (Ministerio de Energía, Actualizacion 2022 Politica Energetica Nacional, 2022). Universal energy access is considered to have been achieved in Chile, but some households in certain regions only have access to electricity for a few hours a day. The aim is to achieve permanent energy access for all households by 2030 (Ministerio de Energía, Actualizacion 2022 Politica Energetica Nacional, 2022). Chile also aims to achieve greenhouse gas neutrality by 2050, a goal reflected in the country's climate strategy and climate change framework laws. The energy sector is responsible for about 77 % of Chile's GHG emissions and is therefore key to achieving this goal. Chile's decarbonization plan foresees large investments in renewable energies, the modernization of the electricity system and market, and the transmission grid (Ministerio de Energía, Plan de Descarbonización, 2023).

Hydrogen's role in the national energy transition

Green hydrogen is expected to play a crucial role in Chile's decarbonization and is both an integral part of the country's strategic energy plan and anchored in its NDCs. The "Planificación energética de largo plazo 2023-2027" (PELP) stipulates that the use of green hydrogen should save 24 % of the emissions that would occur in a reference scenario by 2050 in order to achieve greenhouse gas neutrality (Ministerio de Energía, PELP - Planificación energética de largo plazo, 2023). Chile published its National Green Hydrogen Strategy in November 2020 with the aim of achieving this goal (Gobierno de Chile, 2020). This plans to install 5 GW of electrolysis capacity by 2025 and 25 GW by 2030. In addition, the export potential for green hydrogen products is estimated at about 1.05 million tonnes per year from 2030 and 2.10 million tonnes per year from 2040. This strategy is currently being used to draw up an action plan that explicitly provides for public participation in implementing these goals. For the first time in the history of the Chilean energy market, Chile's government has granted subsidies worth 50 million US dollars for hydrogen projects. The initial aim is for green hydrogen to help reduce greenhouse gas emissions in the chemical sector, especially in the explosives industry. In the longer term, options are also seen to use green hydrogen in shipping and aviation, and possible applications are being considered in the mining and fertilizer industries. In addition, there are already about 60 planned projects geared toward exporting green hydrogen products

(Gubinelli, 2021). To start with, these are exclusively private sector projects and not planned by the public sector.

In terms of defining green hydrogen and its derivatives, it is not yet clear whether the same standards should be applied to exports and to local use. A specifically Chilean definition or the development of a Chilean certification system for green hydrogen and its derivatives is currently being discussed. In this context, there is a generally positive view of the European requirements, although the discussions with local experts clearly indicated that Chile would appreciate clarity about any mandatory requirements. In particular, meeting the temporal and geographical correlation requirements of renewable electricity generation plants and electrolyzer operation is considered a difficult challenge due to the considerable bottlenecks in the electricity transmission grid. For this reason, hydrogen projects are currently being designed to be predominantly off-grid. Especially in the Magallanes region in the very south of Chile, which is not connected to the main national grid and has excellent conditions for wind power, all the Gigawatt hydrogen projects there are currently planned to be off-grid. Even though grid connection in northern areas of Chile would make it possible to further reduce the costs of green hydrogen and its derivatives, priority is currently given to ensuring local supply and low electricity prices.

Targeted synergies and potential risks for the local energy transition

In addition to European partners, there is international cooperation with South Korea and Japan as well as the World Bank and the Inter-American Development Bank. According to local experts, such hydrogen-related cooperation and especially the technical advice from Germany on regulation, standards and studies have made a huge contribution to raising Chile's awareness of the energy transition and to advancing it. The discussions on green hydrogen have led to some measures being taken that are just as important for the overall energy transition. These include topics such as the coal phase-out, the reliability and predictability of renewable energies in the power system, but also determining Chile's potential for renewable energy generation. The latter is estimated to be about 15 to 17 times Chile's expected electricity demand. Land availability is therefore not seen as a bottleneck. Transmission capacities, on the other hand, are already limiting the feed-in of renewable energies. In the Antofagasta and Atacama regions in the north of the country, for example, there have been frequent curtailments in recent months because of insufficient transmission capacities to the industrial centers in Chile’s interior. There is enormous potential for generating solar power in northern Chile. This would ideally be complemented by the wind power capacities in central and southern Chile to produce hydrogen, but these hydrogen projects are unlikely to be economically feasible if transmission capacities are limited and transmission fees are too expensive. In the northern part of the country, the production of hydrogen derivatives is additionally hindered by the shortage of water and hardly any existing sustainable carbon sources. The already congested electricity transmission grid could therefore be additionally burdened by hydrogen projects. This would result in problems for the local electricity supply and electricity price development. However, due to the lack of transmission capacities, the prices for PV electricity in the north are close to zero for several hours a day. If hydrogen projects in the north were mainly based on this local solar energy, which would otherwise often be curtailed, this could trigger new local economic opportunities in a less industrialized part of the country.

Chile has received a lot of international attention in recent years due to its early moves toward a green hydrogen economy and its huge potential for renewable energy generation. However, there is growing concern in Chile that it will be left out or will only be a runner up both as a potential hydrogen exporter and technology importer, especially due to the regulatory positioning of major industrialized nations in the emerging global hydrogen market, e.g., the USA's Inflation Reduction Act. This, in turn, causes great uncertainty for the country's energy planning and infrastructure development processes. Here, local experts expressed the desire for greater commitment on the part of its cooperation partners in order to make projects actually capable of being financed and implemented. In addition, they would like the market ramp-up of green hydrogen in Chile to be sustainable and democratic in the long term, with high levels of local participation and value creation. This is very evident, e.g., in the Magallanes region in the south of the country. Large hydrogen projects would bring enormous landscape and infrastructural changes to this very remote region, so that the social acceptance of export-oriented hydrogen projects and renewable energies in general could be severely affected if the local population is not involved in the decision-making processes. The emerging hydrogen industry should therefore find other and more inclusive approaches and business models than the mining industry has done in the past.

4.3 India

National objectives of the local energy transition

In 2020, renewable energies accounted for about 9 % of primary energy consumption in India. In electricity generation, the share of renewables including large hydropower was 19.7 % in 2020 (BP, 2021). The most important primary energy source in India is coal. The capacities of coal-fired power stations are still being expanded. By 2030, however, India wants to increase the share of non-fossil power generation capacity to 50 % and expects to require an additional demand of 500 GW of installed non-fossil power generation capacity. Currently, about 175 GW of renewable power generation capacity is installed including 46 GW of large hydropower. Universal access to energy has almost been achieved with 99.6 % in 2021 (Worldbank, 2023). India has pledged to achieve greenhouse gas neutrality by 2070. However, there is a lack of clarity regarding the long-term goals of the energy transition and the concrete steps involved in its implementation. Even though the necessity of climate protection has been acknowledged in India, climate protection is not a dominant topic, either politically or socially.

Hydrogen's role in the national energy transition

India launched its National Green Hydrogen Mission in August 2021. This aims to create export opportunities for green hydrogen products, decarbonize sectors in industry, mobility and energy, reduce dependency on imported fossil fuels and raw materials, develop domestic production capacities, create employment and develop cutting-edge technologies. The mission also aims to support pilot projects in emerging final consumption sectors. Regions that are in a position to support the production or use of hydrogen on a large scale should be identified and developed as centers of green hydrogen. By 2030, the goal is to produce at least 5 million tonnes of green hydrogen per year with an associated capacity expansion of renewable energies of about 125 GW. India also intends to develop domestic production capacities for electrolyzers and to install an electrolysis capacity of 60 to 100 GW. The mission will initially involve replacing gray hydrogen by green hydrogen in fertilizer production and oil refining as well as blending green hydrogen into urban gas distribution systems. In a second phase, depending on the development of costs and demand, the use of hydrogen to decarbonize other sectors will be examined: steel production using green hydrogen and the use of synthetic fuels derived from green hydrogen to replace fossil fuels in various sectors including mobility, shipping and aviation (Government of India, 2023). The Mission Secretariat, headquartered in India's Ministry of New and Renewable Energy, is responsible for overall coordination and implementation of the Green Hydrogen Mission and is supported by other sectoral Ministries. An Empowered Group, chaired by the Cabinet Secretary, has been set up to monitor the progress made and, if necessary, correct the objectives of India's hydrogen strategy. An advisory group, which comprises experts from academic, industrial and civil society organizations and is chaired by the government's Prinicipal Scientific Advisor, supports and advises the Empowered Group.

Targeted synergies and potential risks for the local energy transition

In India, too, there is also no willingness to pay more for "green premium products". In several branches of industry, especially the fertilizer industry, which has so far relied on imports, there are economic reasons for switching production to fertilizers based on green hydrogen given the expected reduction in green hydrogen costs. To create demand and stimulate the production of green hydrogen, the Indian government plans to specify a minimum consumption percentage of green hydrogen or its derivatives for designated consumers as energy or feedstock. A mandatory blending ratio for green hydrogen in enterprises that have a high utilization of gray hydrogen, similar to the blending obligations for biofuels, could be a suitable regulatory element to support the entry into a green hydrogen economy.

India's ambition to become the biggest exporter of green hydrogen in the world could provide huge momentum for the expansion of renewable energies. A major challenge in this regard is the country's high level of land parcelization as well as potential land use conflicts. Against this background, the expansion of offshore wind and the use of agrivoltaics are also being considered to produce green hydrogen. So far, there are hardly any concrete statements about how hydrogen projects should be considered in energy planning processes, but hydrogen is included in the initial energy plans of the central electricity planning authority (Government of India, 2023). Given the targeted production volumes for green hydrogen, however, enormous additional generation demand and loads on the existing infrastructure are to be expected. In addition to this, it is projected that there will be a rapidly rising energy demand of the population and industry in India in general. In view of the current high share of coal-fired power, meeting this demand using renewable power will require the expansion of renewable energy capacities on a huge scale. In order to be able to meet the related challenges of expanding the corresponding energy infrastructure, India's central electricity planning authority has asked for international support through technical cooperation.

India's government plans to provide state aid only for national uptake, i.e., the local use of hydrogen. It is therefore likely that export-oriented projects will be designed to serve both national as well as international interests in order to obtain government aid for construction and commissioning. India recognizes the EU's requirements for imported green hydrogen products. In addition, India has elaborated its own definition of green hydrogen, which allows the use of grid power to operate electrolyzers at least temporarily, provided this does not exceed an emission value of 2 kg CO_2/kg H_2 (National Green Hydrogen Mission, 2023). Regarding the currently high share of coal-fired power in India's electricity mix, however, even a temporary use of grid power for electrolysis would lead to the produced hydrogen having a worse climate footprint than that of gray hydrogen. Local experts assume that the flexible operation of electrolyzers and the associated greenhouse gas emissions will be necessary at least temporarily to realize the market ramp-up in India, especially for local use. Despite this, there are no fears that hydrogen production will slow down the phase-out of coal or reinforce fossil infrastructure. As soon as green hydrogen has actually reached an influential market size, actions and corrective measures would be taken. No official statements have been made in this respect to date. This position shows that India's interest in the emergence of a green hydrogen market is primarily an economic one.

4.4 Kenya

National objectives of the local energy transition

Kenya's energy supply is largely based on renewable energies. In 2019, renewables accounted for 68.1 % of Kenya's final energy consumption. The share of renewables in electricity generation even reached 93.5 % in 2020 (IEA, 2023). This is mainly due to the use of geothermal energy for electricity generation, which could be expanded even further. In total, Kenya has a geothermal electricity generation potential of about 10 GW. Furthermore, Kenya's energy mix is extremely diversified. The use of geothermal energy makes a more stable base load possible and can help to balance intermittent solar and wind energy. Universal access to clean energy has still not been achieved in Kenya. In 2021, 76.5 % of households had access to electricity (Worldbank, 2023). The original goal of achieving universal access by 2022 was not met and has now been postponed until 2026. In September 2023, Kenya made an official commitment to reach greenhouse gas neutrality by 2050. It is one of the few countries globally, whose strategies and measures are considered compatible with the Paris Agreement (Climate Action Tracker, 2023). Kenya is pursuing the objective of transforming its national energy system into 100 % clean energy by 2030, but also indicates that its definition of clean includes mostly renewables, but also the use of "cleaner" fuels to stabilize the grid and provide base load power, such as liquefied natural gas. To realize this goal, Kenya has been following its national energy strategy of 2018, which is due to be revised for the first time in 2023 (Ministry of Energy and Petroleum, 2018). This is supplemented by a national strategy for electrification, energy efficiency measures and sectoral strategies for clean cooking technologies and biofuels. The national energy strategy unites all these other subordinate strategies. So far, hydrogen has not been included in the national energy strategy. The issue of energy security plays a crucial role in Kenya. For many years, a low electricity tariff policy was pursued, which counteracted the further expansion of renewable energies. Since the national power utility has been in the red for some time for various reasons, electricity prices were increased in April 2023. This has also resulted in a moratorium on new renewable energy projects.

Hydrogen's role in the national energy transition

Kenya has launched a program of hydrogen development. A National Hydrogen Roadmap was published in September 2023 (Republic of Kenya, 2023). This does not yet include any explicit targets for the expansion of electrolysis capacities or for the decarbonization of sectors through hydrogen use. Export goals have also not yet been defined. For the export market to Europe, Kenya considers itself less competitive than other countries due to its more distant location and inadequate infrastructure connections, and sees more opportunities in the regional market. The fertilizer sector, in particular, could provide Kenya a good entry point to the green hydrogen market. Agriculture is the sector with the highest greenhouse gas emissions in Kenya, accounting for 36 % (Republic of Kenya, 2023). These agricultural emissions could be lowered by expanding a local fertilizer industry based on green hydrogen. However, there is currently no market for green premium products in Kenya. An increased willingness to pay for climate-friendly products is only likely to develop in Kenya through global mechanisms, such as a global CO_2 tax. Nevertheless, Kenya is also very interested in opportunities to develop a green steel industry as well as sustainable aviation fuels.

Standards or regulatory requirements for the production of green hydrogen do not yet exist in Kenya. The EU's definitions of green hydrogen will not affect Kenya's hydrogen production to start with due to Kenya's strategy of focusing on a regional market. Later on, however, it does not rule out getting involved in exports. The aim is to develop regulatory frameworks in the course of implementing the Hydrogen Roadmap. The German government is supporting this process through technical cooperation projects that also focus on training skilled workers.

Targeted synergies and potential risks for the local energy transition

Energy planning in Kenya is to consider hydrogen production as additional electricity demand. To start with, excess capacity from geothermal energy will be used for this purpose, but additional expansion of renewable energy capacities will also be further promoted. The cost of generating electricity from geothermal is generally higher than the lowest costs of wind and PV electricity. However, the higher full-load hours could help lower the cost of hydrogen in Kenya. According to one study, competitive hydrogen production costs of 3.7-9.9 Euro/kgH_2 are currently achievable in Kenya (Müller et al., 2023). Geographically, mainly the north of the country has the potential to further develop geothermal energy as well as wind and solar energy. If the plans to produce green hydrogen become more concrete, electricity transmission capacities from the north to the south as well as from the east to the coast should be expanded. By entering the green hydrogen market, Kenya expects to improve its national power supply security in the medium term. Grid expansion driven by the interest in green hydrogen production could make Kenya less dependent on electricity imports from neighboring countries to stabilize its regional grid and could foster the interconnectivity of an East African Power Trading Pool at the same time. The main concern for Kenya with respect to green hydrogen is the security of supply. However, this not only concerns the goal of energy security, but also the hope to improve food security in the country by using green fertilizers and to make it less dependent on global supply chains.

Land use conflicts over areas suitable for the deployment of renewable energies are a major challenge of the energy transition in Kenya. Fertile land is often privately owned in Kenya, which makes it relatively easy to lease or allocate it to project developers. Land in arid areas that is well suited for solar and wind farms is often held in trust by the regional governments. However, livestock farmers practicing pastoralism are also often part of the local community. This makes it more difficult for project developers to lease large contiguous tracts of land, as it is almost impossible to identify the clear owner of the land and be able to compensate them. Renewable energy projects and hydrogen projects will therefore compete for land at least to some extent and could slow each other down. Financing renewable energy projects is already problematic in Kenya due to its poor credit rating. As hydrogen is still a very new topic of discussion in the country and developments are still uncertain, there has hardly been any investment interest so far. However, Kenya would like to establish a central point of contact as a “one-stop shop” early on to simplify the bureaucratic steps and approval procedures for implementing hydrogen projects.

In summary, Kenya has very serious ambitions to transform its national energy system into one based exclusively on clean energy by 2030, and to reduce its greenhouse gas emissions in other sectors using green hydrogen, particularly in agriculture. Mitigating risks for private investors (de-risking) is one of the biggest challenges in implementing the local energy transition. Conditions for private investment in renewable energy and green hydrogen could be improved by further developing legal requirements with a focus on regulatory and bureaucratic efficiency. Here, there is the need for support from international partners.

4.5 Morocco

National objectives of the local energy transition

The energy system in Morocco is heavily dependent on conventional energy generation, especially on oil, coal and natural gas. Universal access to energy has been achieved in Morocco, even in rural areas. Renewable energies made up about 11 % of total final energy consumption in 2019, and about 30 % of electricity generation in 2021 (IRENA, 2022). The interim target of the 2009 energy strategy, which aimed at a renewable energy share of 42 % in installed electricity generation capacity in 2020, has clearly not been achieved (Royaume due Maroc, 2009). Therefore, it is still open whether other ambitious goals of this strategy can be achieved, such as reaching a renewable energy share of 52 % in installed electricity generation capacity in 2030 and of 80 % in 2050, as well as the target set by the “New Development Model” of meeting 40 % of total final energy consumption using renewable sources by 2035 (Royaume du Maroc, 2021). That the significantly cheaper renewable energies have not penetrated the electricity sector to a greater extent is at least partly due to existing long-term power purchase agreements for expensive coal-based power generation, which is dependent on imported coal. Energy security plays a greater role in Morocco than the energy transition. Cost incentives and working to convince people that an energy system based completely on renewable energies is functional and stable are therefore regarded as important drivers of the energy transition in Morocco. Entering a green hydrogen market and the resulting economic development opportunities this brings could be an additional incentive to advance the energy transition in Morocco.

Hydrogen’s role in the national energy transition

Morocco was one of the first non-OECD countries to come up with a hydrogen strategy. The roadmap “Feuille de route de hydrogène vert” was published in January 2021 and is scheduled to be updated during 2023 (Royaume du Maroc, 2021). The roadmap defines expansion targets in two scenarios, a reference scenario and an optimistic scenario. According to these, renewable energy capacities for green hydrogen production should be expanded by between 8 and 14.6 GW by 2030 and by between 78.2 and 131.5 GW by 2050. This is expected to require 2.8 to 5.2 GW of electrolysis capacity in 2030, and 31.4 to 52.8 GW in 2050. The roadmap describes export opportunities and local utilization options equally. In contrast to the majority of strategies in other countries, the Moroccan hydrogen roadmap contains clear sectoral decarbonization targets. In the short term, green hydrogen is to be applied in industry and in transport in the longer term. The fertilizer industry is likely to be the first business case, as

Morocco is currently one of the biggest importers of ammonia in the world. Especially in view of the disrupted fertilizer supply chains caused by the Russian war of aggression, the chance to become independent of ammonia imports is a promising goal for Morocco. The state-owned fertilizer company, OCP, has announced investments of about 13 billion euros and is planning to produce about 4 million tonnes of green ammonia per year by 2035.

Targeted synergies and potential risks for the local energy transition

Although there are no clear buyers so far, a large export market for green hydrogen products is expected, mainly to the EU. According to local experts, Germany, in particular, is signaling high demand, although there are no German project developers in Morocco to date. In order to meet the EU's requirements, a Moroccan certification system is to be developed for international trade. It is being discussed whether there should be additional national standards, for example, for OCP, or whether the Moroccan certification should be based exclusively on international standards. Local experts consider the latter to be more likely. It can be assumed that investments in wind and solar parks in the foreseeable future will be earmarked exclusively for green hydrogen products, since this will make it easier to prove additionality and because off-grid regions are particularly suitable. This is also able to avoid regulatory uncertainties and costs such as grid charges and connection procedures. In addition, the potentials to generate renewable power are considered very good in many off-grid regions as is land availability, so that competition is not expected between the expansion of renewable energies for the local energy transition and their expansion for hydrogen production in terms of sites or investments. Local experts therefore assume that the energy transition in the electricity sector and the hydrogen market ramp-up will be mutually beneficial, and that this will not result in any loss of momentum in the "electricity transition". Nevertheless, in addition to the earmarked stand-alone solutions, renewable power taken from the grid and hybrid solutions are also relevant within the Moroccan hydrogen strategy. So far, the national strategy to expand renewable energies in the electricity grid has not been elaborated in terms of area, time or sequencing of instruments, although a robust medium and long-term energy plan would require this.

One reason for this is that Morocco does not want to make large-scale investments in the hydrogen market as long as the actual market demand remains unclear. For the Moroccan energy transition, this means that hardly any renewable energy investments are being redirected toward hydrogen projects and that the use of direct electrification for decarbonization is being prioritized across sectors. In general, energy-sector considerations and energy security are paramount according to local experts. International cooperation should therefore be aimed at creating cost incentives for the energy transition in Morocco, for example through climate funds, to level out comparative disadvantages. This must address contentious issues as well as the actual interests of international partners. With regard to the hydrogen market ramp-up, there is therefore a clear expectation in Morocco that investments must come from private, foreign investors. Morocco will try to attract such investment.

4.6 Namibia

National objectives of the local energy transition

Despite its enormous potential for renewable energy generation, Namibia is currently still heavily dependent on energy imports. At present, about 70 % of Namibia's electricity demand is obtained from the neighboring countries of Zambia, South Africa and Zimbabwe. This electricity is based mostly on coal-fired generation. On top of this, there is a large electrification deficit. In 2015, only 51.6 % of households had access to electricity. This is especially noticeable in rural areas, where the share is only 31.3 % (Worldbank, Electrification Indicator Namibia, 2023). Namibia is striving to meet its own electricity demand at affordable prices and with low emissions. The national electrification strategy plans to achieve universal access to energy by 2040. The National Integrated Resource Plan (NIRP) aims to reduce Namibia’s dependency on imported electricity and plans for the country to be self-sufficient by 2028 by expanding domestic generation capacities. Renewable energies already made up a significant share of Namibia's energy mix in 2019, accounting for 30.7 % of final energy consumption and 96.7 % of national electricity generation (International Energy Agency, Country Profile Namibia, 2023). While Namibia has set itself the target of reducing its GHG emissions by 91 % by 2030, the main objective of the national energy transition strategy, the NIRP, is not to achieve greenhouse gas neutrality, but to support the development of the local economy. Renewable energy is clearly the most cost-effective option for Namibia to meet its energy needs. The energy transition therefore has generally high political relevance in the country. Green hydrogen is a novel and additional topic and Namibia has good prerequisites to become a pioneer for renewable energies and green hydrogen.

Hydrogen’s role in the national energy transition

Namibia’s Ministry of Energy published a national hydrogen strategy in autumn 2022, which was developed in cooperation with the German government (Republic of Namibia, 2022). The goals of this strategy are clearly export-oriented. Namibia primarily wants to export hydrogen products that can be transported by ship at low costs, such as ammonia, methanol, and synthetic kerosene. However, there are also concepts to use hydrogen locally for the decarbonization of the transport sector and more sustainable industrialization. Namibia aims to create a large-scale green fuel industry with a production target of 10 to 15 million tonnes of green hydrogen per year based on an electrolysis capacity of 128 GW by 2050. Given Namibia's currently installed power generation capacity of about 700 MW, achieving these goals will require huge expansion of renewable energy capacities and a drastic transformation of the present infrastructure (IRENA, Energy Profile Namibia, 2023). Accompanying this are high hopes that Namibia will experience an economic upturn due to the great interest in hydrogen expressed by international project developers and that local energy supply problems will be resolved in the process more or less as a side effect. Project developers such as “Hyphen Hydrogen Energy”, who are planning a project to produce green hydrogen in the south of Namibia with a renewable capacity of 7 GW and an electrolysis capacity of 3 GW, have declared that the entire Namibian power grid could be decarbonized with the surplus electricity they will be able to generate (Hyphen, 2023).

Targeted synergies and potential risks for the local energy transition

According to local experts, in order to actually realize such proclamations, the Namibian government's strategy needs to establish a link between hydrogen and energy access as well as clearer responsibilities and explicit requirements for hydrogen projects to improve energy access in the country. Namibia’s hydrogen strategy should also be expanded to include a section that explicitly explains how the Namibian population stand to benefit from the planned large-scale projects. The development of local value chains should give the country sustainable growth impulses. The government also announced that it will use revenues from hydrogen exports to drive socio-economic change through basic investments in education and infrastructure, as well as investments aimed at the development of local industry. However, there are no clear guidelines yet on how and where these revenue flows should be directed.

Namibia's primary trading partner for hydrogen-based export products is the European Union, but China, Japan and South Korea are also interested in possible hydrogen cooperation with Namibia. The aim is to meet the EU's requirements for producing green hydrogen products in Namibia. A national strategic and legislative framework is to be developed by March 2025. This framework will define standards for synthetic fuels and legal requirements for hydrogen projects to ensure compatibility with international standards. Using electricity from the grid is hardly an option to improve electrolyzer utilization rates given the defined export targets, so project developers plan to rely exclusively on additional, oversized PV and wind power plants, also in view of the large areas of land available with little competition for its use, simple land allocation processes and the potential for high full-load hours. Establishing an "Implementation Authority Office" and modified services is intended to create clear, transparent, and user-friendly processes for all parties involved in the planning and implementation of hydrogen projects.

In addition to intercontinental trade, Namibia aims to create an integrated, thriving green economy throughout Southern Africa. To this end, synergies are to be created in terms of joint infrastructure, production collaboration and electricity exports, e.g., with South Africa, Botswana, Zambia and Angola. Within the framework of the Southern Corridor Development Initiative, Namibia is participating in the development of a Common Use Infrastructure for the first large-scale hydrogen projects in sub-Saharan Africa. This will include overland pipelines, water infrastructure, hydrogen pipelines, ancillary infrastructure, and industrial port complexes.

There are huge opportunities for a green hydrogen industry in Namibia that are accompanied by correspondingly large expectations and challenges in the country and the entire region. However, to enter the green hydrogen market, Namibia needs binding financial and technical support from international donors, who must not ignore the challenges with regard to energy access in the country.

4.7 South Africa

National objectives of the local energy transition

The energy system in South Africa is largely based on coal. Renewable energies (excluding hydrogen) made up about 7.3 % in 2022, a relatively low share of the electricity generation (CSIR, 2023). South Africa has a dedicated strategy to increase the share of renewable energies in the grid with its Integrated Resource Plan, IRP, and the Renewable Energy Independent Power Producer Procurement Programme, REIPPPP. According to the most recent IRP from 2019, solar and wind energy should have a combined share of 34 % in the energy mix by 2030. However, it is currently unclear whether these targets can be achieved, since the expansion of renewable energies is lagging behind the interim goals. So far, hydrogen is not included in the Integrated Energy Plan IEP, which was last updated in 2016 (Republic of South Africa, 2016). Updating the IEP is essential for guiding the country's overall energy planning, including the development of hydrogen infrastructure. The IEP is decisive for investments in energy infrastructure and the development of policy measures. Despite plans, targets and programs, there is a lack of government commitment to set clear incentives for phasing out coal. Many coal-fired power stations will have to be shut down over the next three decades, which means that less than 10 GW of the existing capacity will still be in operation by 2050. In addition, the technical availability of the existing power stations is declining continuously due to their high average age, while the expansion of renewable energies is only progressing with significant delays. This has led to considerable load shedding for many years. Despite significant improvements in terms of grid access since the 1990s, there is still an electrification deficit. In 2021, approx. 89 % of households had access to energy (IRENA, 2023). The energy transition in South Africa is therefore currently mainly driven by the issue of energy security rather than the need for decarbonization.

Hydrogen's role in the national energy transition

With the global attention around hydrogen, South Africa sees a huge opportunity for the climate-friendly transformation of its industry. The South African cabinet passed the Green Hydrogen Commercialisation Strategy in November 2022 (Republic of South Africa, 2022), which updated and further specified the partly too optimistic goals of the Hydrogen Society Roadmap from 2021 (Republic of South Africa, 2021). The strategy plans to give priority to exporting green hydrogen and green chemicals. This should build on the expertise of Sasol in Fischer-Tropsch synthesis. Sasol operates both gas-to-liquids and coal-to-liquids plants to produce synthetic fuels, although coal makes up the bulk of the feedstock. Green hydrogen could replace this production of gray or black synthetic fuels. The planned export of green hydrogen derivatives can therefore also drive the decarbonization of local industries in South Africa. In addition to petrochemicals, South Africa is also pursuing options to use green hydrogen in the fertilizer and steel industries as well as in emergency power supply and in the heavy-duty transport and mining. However, local experts expect that green hydrogen products will struggle on the South African market without incentive schemes. The intention is to stimulate the local market for green hydrogen in South Africa by setting emission limits for sectors and companies as planned in the South African Climate Change Bill or through binding quota systems for synthetic fuels. South Africa does not have its own definition of green hydrogen or its own certification scheme. The European requirements for hydrogen products are regarded as very restrictive. However, the export market of the EU is very important for South Africa, especially for products such as green steel, which should enable high value creation in the country.

Targeted synergies and potential risks for the local energy transition

Local experts currently assume that the production of green hydrogen will be supplied by additionally constructed renewable generation capacities and that grid power will not be used for the time being. It is expected that the additional renewable energies constructed for hydrogen projects will be oversized and could feed in surplus electricity into the grid. To optimize the utilization of electrolyzers, local experts consider battery storage a possible solution that is independent of the supply uncertainties when using grid power. However, so far there are no dedicated strategies or specific targets for this.

Hydrogen projects can have both positive and negative effects on local energy infrastructure. The expansion of renewable energies in South Africa is already extremely restricted by bottlenecks in the transmission network so that not all the tendered generation capacities can be realized due to missing transmission capacity. The production of green hydrogen could exacerbate this problem, especially if the wind and solar power plants and the electrolyzers were not located close to each other and had to use scarce transmission grid capacities. One way to avoid additional strain on the power grid could be a regulatory ban on grid-connected hydrogen projects as long as the energy crisis lasts. However, hydrogen projects can also serve as an incentive to accelerate grid expansion in order to exploit more export potential. For example, there are some concrete ideas to create incentives for hydrogen project developers to finance grid expansion themselves through investments by offering them reduced transmission tariffs in the long term as anchor clients, since the state grid operator ESKOM has the mandate, but does not currently have the financial resources for grid expansion. Integrating hydrogen into the strategic planning of the national power transmission grid is therefore urgently needed to ensure that the electricity demand of hydrogen projects is included in grid expansion planning. At present, this is not the case.

The effects with respect to land use conflicts are also unclear. To a large extent, farmers lease land directly to project developers without involving the regulatory authorities. Project developers only have to prove that there are no other claims to the land. Many independent power generators analyzed areas with high potential to produce renewable power years ago, and some approved projects. Due to slow state expansion plans and bidding procedures for the local electricity system, many of these very good locations have still not been put to any use. Hydrogen production now offers an alternative business model. However, re-purposing these areas may be problematic for local energy supply and therefore also for the local energy transition in the longer term. This may not only lead to physical conflicts of use, but a massive expansion that is possible in physical terms may create or worsen acceptance problems among the (local) population. This problem is perceived locally to some extent, but has not yet been systematically addressed politically.

Local experts see the biggest opportunity for the local energy transition through hydrogen in improving South Africa’s investment opportunities. Green hydrogen gives the country the chance to protect its existing export-oriented economy, to generate revenue and to promote sustainable investment in the country’s dilapidated energy infrastructure in the course of a green reindustrialization. However, this would require regulatory guidelines for the use of export revenues and greater clarity with regard to roles and responsibilities. South Africa would like to take advantage of the high level of international attention to attract investment. International cooperation such as the Just Energy Transition Partnership between South Africa and various development partners such as Germany, France, Great Britain, USA and EU could support the development of the hydrogen sector in South Africa by providing financing.

4.8 Tunisia

National objectives of the local energy transition

Despite Tunisia having great potential for renewable energy generation, its energy system is still largely based on fossil fuels. Renewables only accounted for 3.9 % of electricity generation in 2020 (International Energy Agency, Country Profile Tunisia, 2023). In terms of primary energy consumption, the share of renewables is even lower. Universal energy access has been achieved, but Tunisia is likely to be confronted with a rising energy deficit, which could affect the local security of supply in the long term. Natural gas imported from Algeria is the most important primary energy source for Tunisia’s energy system. In October 2022, Tunisia published a "Strategy for carbon-neutral development and resilience to climate change", which describes the pathways and approaches to becoming GHG-neutral by 2050, and complies with its international climate commitment in the Paris Agreement (Republique tunesienne, Stratégie de Développement Neutre en Carbone et Résilient aux Changements Climatiques à l'horizon 2050, 2023). In March 2023, Tunisia announced new objectives with regard to its energy strategy. As far as renewable energy is concerned, Tunisia plans to install an additional capacity of 8350 MW by 2035 (Webmanagercenter, 2023). The energy transition is considered extremely important, but there are no clear responsibilities for driving the fundamental transformation of the Tunisian energy system. The green hydrogen sector, under the supervision of the General Directorate of Electricity and Energy Transition at the Ministry for Industry, Mines and Energy, seems to be developing faster than the renewable energy sector.

Hydrogen's role in the national energy transition

Tunisia began developing its national hydrogen strategy in mid-2022, which is to be published before the end of 2023. Tunisia's Hydrogen Strategy and Energy Transition Strategy are to be closely linked through workshops and knowledge exchange, so that hydrogen activities can be harmonized with initiatives for the energy transition. The strategy envisions the creation of a hydrogen task force within the Ministry of Industry, Mines and Energy to develop a Tunisian hydrogen sector. Tunisia has already announced that it wants to prioritize exports in the medium term in order to use them to develop the market for local use. This not only includes green hydrogen but also renewable energy in general. The strategy aims at exporting 6 million tonnes of green hydrogen products per year by 2050 and plans an additional 2 million tonnes of hydrogen per year to meet domestic demand. The European Union is seen as the main trading partner. Tunisia plans to sign an agreement to enable long-term purchase contracts for green hydrogen products with the European Union. A large part of the financing for the corresponding infrastructure development is also to come from EU funds. Both sides are aiming to develop a pipeline connected to the planned European Hydrogen Backbone (SoutH2Corridor, 2023). The European requirements for green hydrogen products are very relevant for Tunisia due to its strong focus on exports to the EU. To meet these requirements, primarily off-grid projects to produce green hydrogen are currently being planned.

In addition, Tunisia is the second largest importer of ammonia in Africa after Morocco. Tunisia therefore currently sees opportunities for the local use of green hydrogen products primarily in the transformation of its fertilizer industry. At present, however, most of the fertilizers produced in Tunisia are exported to India, where there is currently no interest in green products at higher prices. Great potential for using hydrogen is also seen in shipping, which is of enormous importance for Tunisia's foreign trade. With forward-looking planning, it would be conceivable to use green ammonia or methanol in shipping as one component of Tunisia's decarbonization. In order to achieve the decarbonization goal, existing port infrastructure in Tunisia, which urgently needs to be modernized in the coming years anyway, must first be expanded (GIZ, 2021). However, where possible, decarbonization measures should prioritize direct electrification over the application of hydrogen downstream products.

Targeted synergies and potential risks for the local energy transition

There are some international cooperation projects, especially with Germany, Austria and UNIDO that support the acquisition of skills and the ramp-up of local demand. Tunisia would particularly appreciate international support with the development of a local hydrogen value chain, as there are not enough government resources available for this. However, there is a clear focus of international cooperation in Tunisia on the implementation of large-scale projects to export hydrogen products. The potential revenue from these exports should help to boost local efforts to expand renewable energies, but so far there are no specific plans to ensure that this actually takes place. A study has been commissioned to analyze the benefits Tunisia stands to gain from an economy based on hydrogen exports.

The development of renewables in Tunisia is still slow and possible interdependencies between entering green hydrogen production and the expansion of renewables are currently difficult to foresee, although Tunisia’s green hydrogen strategy has been designed to align with other strategies including those for the energy transition, water and decarbonization. Tunisia's economic interest in entering the green hydrogen economy is very high and this ensures the political and regulatory willingness to act. As a result, some important processes have already been initiated to improve local planning and implementation capacities. The expansion of renewable energies for local energy supply can also benefit from this. However, there could also be a risk that the (limited) capacities are mainly used to produce green hydrogen and less to expand renewables for local energy supply. Competition for suitable sites between renewable energy projects and hydrogen projects is seen by local experts as the greatest risk to implementing the local energy transition if sites are primarily used for export-oriented hydrogen production. To avoid land use conflicts, the Green Hydrogen Strategy proposed the establishment of an agency to be responsible for land allocation for renewable energies and to speed up permit issuing procedures. This agency, as well as the above-mentioned task force, should ensure that green hydrogen expansion does not hinder the growth of renewable energies.

5 Discussion and Conclusions

The objective of this Working Paper was to compile possible interdependencies between national energy transitions and the development of an (at least partially) export-oriented hydrogen economy and to highlight important aspects of these interdependencies. Interviews with local experts showed that they are not always aware of all the interdependencies. Even if they are aware of specific interdependencies, the local political and regulatory framework is often not designed to address them properly.

Clarifying the role of hydrogen in the respective national energy transition is still in its infancy in many countries. A first step is to be more aware of the opportunities and risks involved in order to take them into account in the further design of political and regulatory framework conditions. Opportunities have to be actively taken and risks actively managed - proactive policy is essential to steer both aspects.

The possible interdependencies described in this Working Paper have to be examined in detail in the respective country context. This type of detailed analysis was not possible within the scope of this paper. Instead, the focus was on deriving and describing possible interdependencies from the countries. The following fundamental recommendations can be made on this basis:

- The global objective of entering the hydrogen economy must always be borne in mind: Green hydrogen should contribute to a reduction of global CO_2 emissions. It must be ensured that green hydrogen is actually produced in a CO_2 neutral way (to the greatest possible extent) and from a broad perspective. The consequence of this is that emission reductions in countries importing green hydrogen for their energy transition may not be achieved at the expense of the energy transition in the exporting countries, i.e., it must be ensured that green hydrogen production does not hinder but supports their energy transition. This is also a requirement found in Germany's National Hydrogen Strategy. It must be avoided that hydrogen projects, especially when these are intended for export, lead to already planned energy transition projects being replaced or postponed or to a dwindling acceptance of the energy transition strategy at home. It is also important to avoid an increase in local greenhouse gas emissions due to an export-oriented hydrogen economy, e.g., if grid power based on fossil energy sources is used to meet additional electricity demand.
- Developing capacities and training programs for renewable energies must take equal account of what the local energy transition needs and what entering the hydrogen economy requires. One may not be pursued at the expense of the other. The same is true when developing resources for administrative and permit issuing processes or for the political control and regulation of the sector.
- Entering the hydrogen economy can have significant impacts on the local electricity system. These impacts can often only be estimated by simulating specific grid and operation setups. It can make sense to require such simulations when planning export-oriented hydrogen projects in order to systematically analyze the impacts on the local electricity system.

- At first, it may be possible to avoid negative impacts on the local grid infrastructure by using off-grid solutions when planning export-oriented hydrogen projects. In the medium to long term, however, hydrogen production and use should be integrated into the local energy system and explicitly addressed and included in grid expansion plans.
- The utilization options for green hydrogen must be realistically assessed. Corresponding analyses and considerations are already part of the process of formulating national hydrogen strategies in many countries. Since the market for green hydrogen and hydrogen-based green products is still evolving, these analyses have to be continuously updated and adapted.
- The interdependencies outlined in this paper should be taken into account in international cooperation aimed at supporting entry to the hydrogen economy (so-called international hydrogen cooperation). This is also anchored in Germany's Hydrogen Strategy, which states that the production of green hydrogen in developing countries should be used to stimulate and drive the rapid development of renewable generation capacities in these countries, which in turn will also benefit local markets (Bundesregierung, 2020).
- This Working Paper was only able to consider a limited number of aspects. The country-specific interviews were also only able to shed some light on the issues and do not claim to have covered every aspect. It seems advisable to continue and expand the country-specific analyses of the interdependencies. In particular, these should be incorporated into the development of national hydrogen and energy transition strategies and their updates. These interdependencies should also not be ignored in the international discussion of sustainability criteria and certification. This increases the complexity, but also contributes to making the entry into a green hydrogen economy truly sustainable and to ensuring that significant greenhouse gas emission reductions are actually achieved from a global perspective.

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