
HYPAT



H₂ Potential

Globaler H₂-Potentialatlas

Nachhaltige Standorte in der Welt für die grüne Wasserstoffwirtschaft von morgen:
Technische, ökonomische und soziale Analysen zur Entwicklung eines nachhaltigen
globalen Wasserstoffatlases

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Towards a Green H₂ Economy: Türkiye Country Report

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Key Messages

- Türkiye's Hydrogen Technologies Strategy and Roadmap highlights two main targets:
 1. Reducing the cost of green hydrogen production to less than \$2.4/kg by 2035 and less than \$1.2/kg by 2053.
 2. Increasing the electrolyser installed power capacity to 2 GW by 2030, 5 GW by 2035 and 70 GW by 2053.
- To reach these targets, the main focus lies on the technology development for hydrogen production, storage, distribution and utilization. However, the Roadmap lacks a detailed action plan with clear goals and how these will be achieved.
- In Türkiye, implemented policies and the targets announced by the government on climate action often conflict. A good example is the increasing number and capacity of coal power plants despite the announced net-zero target by 2053 by the President Erdoğan.
- Nevertheless, to establish a green hydrogen economy, there are several factors distinguishing Türkiye from other potential producers of the global market:

1. **Natural, physical and human capital:** Türkiye has very good renewable energy resources. In 2022, 60% of the domestic energy generation was from renewable sources. Pipelines, ports and electricity grid are all modern and well-equipped to support the unfolding hydrogen market. Its young population with high shares of STEM graduates offers great potential.

However, water scarcity may pose one of the greatest challenges for green hydrogen production in Türkiye.

2. **Research and innovation ecosystem:** The research and innovation ecosystem of the country is a well-established one. One of the recent foci of Scientific and Technological Research Council of Türkiye (TÜBİTAK) is on green growth. The Green Growth Technology Roadmap of the Council includes a detailed technology development plan to support the green transformation of all the heavy-industries that are affected by Carbon Border Adjustment Mechanism (CBAM). These technologies also include hydrogen production and carbon capture and storage (CCS). Another important research topic for Türkiye is the boron mineral. Currently the research is particularly focused on its versatile use to chemically store hydrogen.

However, high inflation rate makes it very challenging for firms to invest in R&D.

3. **Local hydrogen demand:** Turkish heavy-industry is the sector with the biggest demand for green hydrogen in the country. Due to CBAM that is going to be implemented by the European Union (EU) as of 2026, heavy-industry manufacturers need to decarbonize their production processes and green hydrogen, in most of the cases, is the only possible option to do so.

However, high levelised cost of hydrogen (LCOH) compared to fossil fuels is the biggest challenge for industry given that no support mechanism is currently in place.

- This country study recommends that immediate action in setting clear and coherent policies is required. Moreover, supportive regulatory framework should be implemented to ensure market development, safety and harmonised standardization.
- Türkiye can also leverage its existing know-how in manufacturing of renewable energy technologies and use this to establish a strong electrolyser manufacturing sector. This can be supported by joint ventures with international manufacturers, accelerating the technology development and attracting foreign direct investment into the country.
- One major area of collaboration with international cooperation is the joint infrastructure development. Existing joint declarations can be utilized to explore collaboration possibilities for regional and bilateral infrastructure projects like pipelines.

1 Introduction and Methodology

1.1 Introduction

The ramp-up of the green hydrogen market is becoming a pivotal focus in the global transition towards sustainable energy. Green hydrogen, produced through the electrolysis of water using renewable energy sources, is heralded as a key solution for decarbonizing sectors that are traditionally hard to abate, including heavy industry, transportation, and power generation. As countries worldwide strive to meet ambitious climate targets and reduce their reliance on fossil fuels, the development of a robust green hydrogen infrastructure is emerging as a cornerstone of future energy systems.

The global green hydrogen market is expected to grow exponentially in the coming decades, driven by declining costs of renewable energy and electrolysis technologies, as well as increasing policy support and investment. Countries are investing heavily in research and development (R&D) to improve the efficiency and reduce the costs of hydrogen production, storage, and distribution. International collaborations and partnerships are also playing a crucial role in advancing the hydrogen economy, facilitating technology transfer, and establishing global supply chains.

Türkiye, with its strategic geographical location and dynamic economic landscape, is well-positioned to become a major player in the green hydrogen market. The country's proximity to both European and Asian markets provides significant opportunities for export and collaboration. Additionally, Türkiye's existing energy infrastructure and industrial base offer a strong foundation for developing a robust green hydrogen economy.

Türkiye's alignment with the European Union's climate policies, particularly the Carbon Border Adjustment Mechanism (CBAM), adds another layer of strategic importance to green hydrogen development. As a major trading partner of the EU, Türkiye stands to benefit from aligning its energy policies with those of the EU, potentially turning its green hydrogen industry into a key economic driver and securing its position in the future low-carbon economy.

Türkiye's foray into the green hydrogen market is supported by its abundant natural resources, strong physical infrastructure, skilled human capital, and growing domestic demand. These elements, combined with proactive governmental policies and strategic international alignments, position Türkiye uniquely in the global green hydrogen landscape. As the country continues to develop and implement its hydrogen strategy, it not only enhances its energy security and economic resilience but also contributes significantly to the global efforts in combating climate change.

This country report aims to provide a comprehensive analysis of the green hydrogen market ramp-up in Türkiye. Through an in-depth examination of policy frameworks (Chapter 2), stakeholders (Chapter 3), opportunities and challenges (Chapter 4), this report seeks to shed light on the evolving landscape of green hydrogen production in Türkiye. Lastly, the report makes some recommendations and identifies strategies to unlock Türkiye's full potential in the global hydrogen economy, with a focus on international cooperation (Chapter 5).

The country report describes one particular aspect of the HYPAT project. The HYPAT project is developing a global hydrogen potential atlas and for the first time comprehensively identifies

possible partner countries of Germany for a cooperative development of a future green hydrogen economy including the importance of the production regions for a secure, economic and ecologically sustainable supply.

1.2 Methodology

In order to reflect a comprehensive and a nuanced discussion, HYPAT country report covers various factors like policies, stakeholders, potentials, capacities and draws analyses on green hydrogen market ramp-up in Türkiye in relation to these factors. To do so, a two-step methodology was used: First, a literature review covering academic studies, related policy documents, strategies and reports was conducted to have a coherent view on the steps that have already been taken in the country in establishing the market. Later, in three different rounds 31 semi-structured interviews were conducted. The first round was comprised of onsite consultations and was done in June and July 2022. The second round was carried out online between September 2022 and January 2023. The last round was planned as another onsite field trip for February 2023, but after a week it had to be cancelled due to the earthquake on February 6th, 2023. Cancelled interviews were rescheduled and conducted online in March 2023. The interviews were conducted with various stakeholders from politics, public institutions, universities, research centres, private sector, industry and renewable energy producers. The interviews were very instrumental in providing an opportunity to bring local experts' opinions into the analysis.

Choice of country

In the scope of HYPAT, the global export potential for green hydrogen and synthesis products are being quantified for all eligible countries. In addition, in-depth studies have been carried out for selected countries.

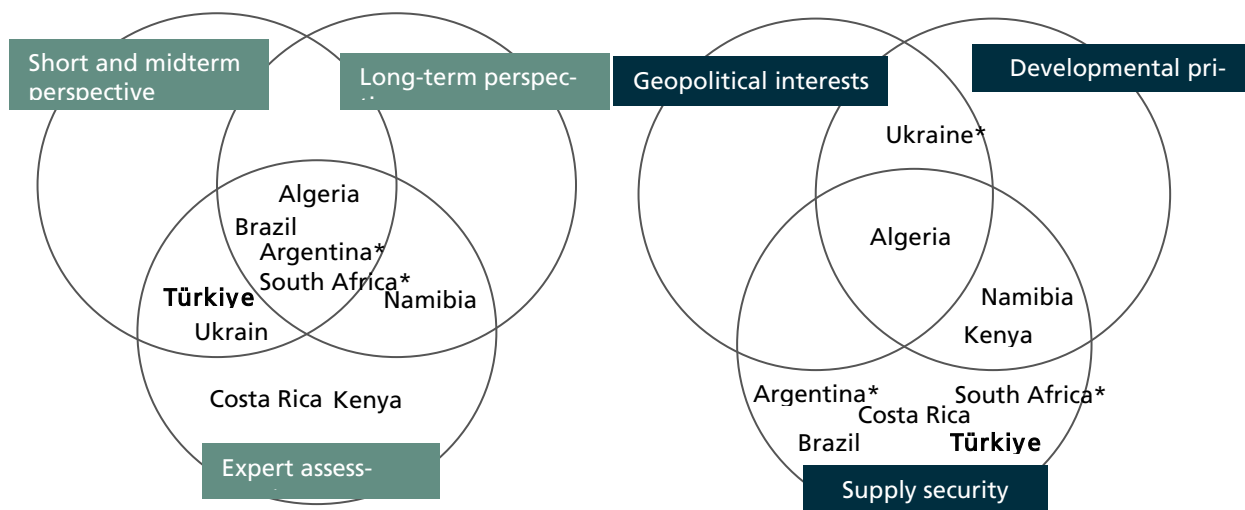


Figure 1. Country selection

The selection of countries for these in-depth studies is based on an indicator-based analysis, considering in total 55 criteria that cover natural, technical, political, institutional and socio-economic aspects (Breitschopf et al., 2022). This initial selection was subsequently validated in a

focus group discussion with regional experts from German and international development policy institutes and think tanks. In addition to certain minimum requirements (political stability, water availability, RE potential), the main criteria for selection were the medium and long-term potential for the production of green hydrogen, security of supply, geopolitical interests and development policy objectives (see Figure 1). Aspects such as geographical proximity to the EU and a low level of study coverage to date were also taken into account.

A balanced regional distribution and representation of the selected countries in terms of region and socio-economic development was considered as well. In particular, the countries for the potential, skills and stakeholder analyses¹ were selected according to their affiliation with one of the following clusters: (1) countries with low/medium gross national income and low industrial base and technological capability; (2) countries with medium/high gross national income and a solid industrial base and technological performance; (3) rentier economies based on fossil fuels. Türkiye belongs to the second country cluster.

¹ The selection of countries for the (primarily empirical-qualitative) potential, competence and stakeholder analysis differs in some cases from the selection for the model-based, quantitative potential survey due to content, methodological and feasibility considerations.

2 Hydrogen strategy and roadmap

In January 2023, Türkiye published its Hydrogen Technologies Strategy and Roadmap (Ministry of Energy and Natural Resources, 2023). The following targets are salient in the strategy:

1. Reducing the cost of green hydrogen production to less than \$2.4/kg by 2035 and less than \$1.2/kg by 2053.
2. Increasing the electrolyser installed power capacity to 2 GW by 2030, 5 GW by 2035 and 70 GW by 2053.

These targets reflect the long-term perspective of Türkiye to establish a hydrogen economy with wide domestic application possibilities, as well as becoming a competitive exporter of low-carbon hydrogen in the international market. To reach these goals and to leverage its existing research and innovation capacities, through the strategy Türkiye signals that it will be focusing strongly on technology development. For this purpose, the strategy presents different roadmaps covering four major technologies along the hydrogen supply chain. These are the roadmaps for hydrogen production, storage, distribution and utilization technologies. The roadmaps follow a parallel timeline from 2023 to 2053, while targeting different milestones.

The hydrogen production technologies roadmap identifies three colors of hydrogen for which a production technology will be developed. These are namely green, blue and turquoise hydrogen (Ministry of Energy and Natural Resources, 2023, p. 14). For green hydrogen production, the roadmap points out different technologies like electrolysers, biogas pyrolysis, biogas reforming, and biological production. While the target for electrolysers is to be able to manufacture the ones with 500 MW to 1 GW capacity by 2053, no target was set for other production technologies.

For blue hydrogen, the strategy targets production both from natural gas and coal combined with carbon capture and utilization (CCU) technologies. Even though Türkiye has coal reserves and wants to leverage its existing domestic resources, the country is almost completely dependent on imports when it comes to natural gas. In 2022, 99% of the domestically used natural gas was imported, 39% of which was from Russia (EPDK, 2023, pp. v–vi). Nevertheless, it is known that the Ministry of Energy and Natural Resources is working on a separate roadmap and implementation plan which will solely focus on both technology development but also deployment of carbon capture storage and utilization in the country (Republic of Türkiye, 2023, p. 4). This underlines Türkiye's reluctance in phasing out domestic or imported fossil-fuel energy sources, while aiming at net-zero emissions by 2053. Moreover, the focus on prioritizing methane pyrolysis as a third production technology also signals the goal of using the byproduct carbon to develop further value-added products.

The hydrogen storage technologies roadmap also focuses on development and adaptation of several different technologies simultaneously (Ministry of Energy and Natural Resources, 2023, p. 15). These include hydrogen storage cylinders, pressurized cryogenic gas hydrogen storage, storage options for liquid hydrogen, storage systems with adsorbents and hydrides as well as storage in the form of ammonia and organic chemicals. It should be also noted that BOTAŞ (the state-owned enterprise operating pipelines and storing gas and LNG) is working on hydrogen storage possibilities in salt caverns under the Lake Tuz (Ministry of Energy and Natural Resources, 2023, p. 11). The roadmap also points out the development of storage technologies

designed specifically for transportation applications of hydrogen (e.g. in road vehicles, marine and aerospace applications) as long-term targets.

For hydrogen distribution, on the other hand, the featured method is the use of existing natural gas pipelines and infrastructure (Ministry of Energy and Natural Resources, 2023, p. 16). To examine the possibility of utilizing Türkiye's natural gas pipeline network to transport and distribute hydrogen, the Association of Natural Gas Distributors of Türkiye (GAZBİR) (2021, p. 28) has conducted a study where they tested up to 20% hydrogen blending in gas pipelines with no technical complication.

Lastly, the roadmap for hydrogen utilization technologies focuses on development of fuel cell technologies for diverse applications like road vehicles, rail systems and aircrafts (Ministry of Energy and Natural Resources, 2023, p. 17). Apart from fuel cells, it also includes developing technologies for natural gas turbines and boilers for different blending degrees. Finally, green hydrogen applications in heavy industry (e.g. petrochemicals, chemical, cement, iron and steel, glass and ceramics) together with applications in transportation were indicated.

While laying out those four roadmaps for parallel development of different technologies, the strategy also identifies a detailed list of needs in reaching those targets and proposes a solution for each. The majority of identified needs cover the challenges related to technology development (Ministry of Energy and Natural Resources, 2023, pp. 10–13). These include, for example, low technology readiness levels (TRL) in aimed technologies, insufficient (or no) domestic manufacturing of system sub-components like catalysts, plates, electrodes and membranes, limited research on the use of boron in hydrogen storage and the need to establish the infrastructure for heavy industry to facilitate its transition from fossil-fuel-based hydrogen to the green one. Similarly, the strategy also points out further needs in developing target-oriented plans for creating industrial clusters, improving research facilities, increasing the number of qualified researchers, engaging in international cooperation and conducting studies on safety (Ministry of Energy and Natural Resources, 2023, p. 13).

Prior to the launch of the strategy, SHURA Energy Transition Center, a research organization focusing on the decarbonization of the energy sector in Türkiye, published two reports in 2021 on the priority areas in green hydrogen deployment in Türkiye and Türkiye's production and export potentials. The former revealed that a total of 4.6 million tons of oil equivalent (Mtoe) hydrogen would be required to decarbonize major end-use sectors in Türkiye like industry, road freight and gas grid, which would be equal to 12.1 GW electrolyser capacity or 36.3 GW power supply (SHURA, 2021a, p. 7). The latter found, on the other hand, that a total green hydrogen production capacity of Türkiye by 2050 can be as high as 3.4 million tons, 1.9 million of which would be consumed by the domestic demand and 1.5 to 1.9 million tons could be exported (SHURA, 2021b, p. 8).

2.1 Other relevant sector policies

In October 2021, Türkiye ratified the Paris Agreement and acceded to it (Presidency of the Republic of Türkiye, 2021). Following the ratification, President Erdogan announced Türkiye's net zero emission target for 2053. Upon both, in 2023 Türkiye updated its first Nationally Determined Contribution (NDC) (Republic of Türkiye, 2023). Below some of the published sectoral policies are explained in detail.

2.1.1 National Energy Plan

Following the 2053 net zero emission target, Türkiye National Energy Plan was published in 2022. According to the plan, the annual gross electricity consumption is expected to reach 510.5 TWh in 2035 (Ministry of Energy and Natural Resources, 2022, p. 21), corresponding to a 35% increase compared to 330.3 TWh in 2023 (Ministry of Energy and Natural Resources, 2024c). Even though the consumption will increase in real terms extensively, the plan projects no significant change in the shares of different sectors within this consumption from 2020 to 2035. For example, the share of industry will increase from 34.4% to 38.7% and that of transport from 25.5% to 26.4%, while the shares of residential and services decrease slightly (Ministry of Energy and Natural Resources, 2022, p. 21). Below, Table 1 represents the projected increase in domestic energy supply to meet the expected growth in demand along with current installed capacities.

Table 1. Current installed power generation capacities and projected increase therein (GW)

Energy source		Current installed capacity (as of December 2022)	Projected capacity (2035)
Renewable energy	Wind (onshore)	11.4	24.6
	Wind (offshore)		5
	Solar PV	9.4	52.9
	Hydropower	31.5	35.1
	Geothermal and biomass	3.6	5.1
Nuclear		0	7.2
Coal	Power plants fired with domestic coal (lignite, asphaltite and bituminous coal)	11.4	24.3
	Power plants fired with imported coal	10.4	
Natural gas		25.3	35.5
Other		0.8	-
Total		103.8	189.7

Source: (Ministry of Energy and Natural Resources, 2022, pp. 15–35; TEİAŞ, 2022)

As seen from Table 1, the plan projects 45% increase in the total installed domestic power generation capacities by 2035. In 2022, Türkiye was able to cover almost all demand with domestic power plants, electricity imports corresponding to 1% of the total demand (IEA, 2024b). Nevertheless, when the National Energy Plan designs an increase in the future shares of imported power sources like natural gas, coal and nuclear, it will be difficult to ensure self-sufficiency for Türkiye in power generation. Moreover, the fact that the former two of these energy sources (natural gas and coal) are fossil-fuel could make the net zero target a difficult one to reach by 2053.

Even though it is claimed that the contribution from natural gas power plants in power generation may vary since they are used to offset the potential generation variations from other sources (Ministry of Energy and Natural Resources, 2022, p. 24), it shows that Türkiye will continue installing new fossil-fuel power plants at least until 2035. Additionally, the plan indicates that there is no fossil-fuel power plant with carbon capture technologies in the pipeline (Ministry of Energy and Natural Resources, 2022, p. 25).

On the other hand, the plan suggests that hydrogen and synthetic methane will be blended in natural gas to lower emissions (Ministry of Energy and Natural Resources, 2022, p. 16). The increase in power generation required for hydrogen and synthetic methane production will be rapidly installed after 2035 and it is expected that this share should correspond to 17.6% of the total electricity consumption (Ministry of Energy and Natural Resources, 2022, p. 32). Additionally, the use of hydrogen and batteries as energy storage medium is also foreseen for ensuring the flexibility in the system (Ministry of Energy and Natural Resources, 2022, p. 26).

2.1.2 Twelfth Development Plan (2024-2028)

Development plans are traditional medium-term strategies that have been published since 1963 and are based on governmental projections both at the global and national levels representing political, economic and social conditions of their time. The Twelfth Development Plan was published in November 2023 and includes a long-term strategy of development (2024-2053) as well as a 5-year-plan (2024-2028) with diverse targets to pave the way for that long-term strategy. The targets for the 5-year plan include the ones for economic growth, green and digital transformation, and qualified workforce.

The plan mentions that the development of hydrogen technologies along the supply chain (production, storage, transport and upstream applications) will be supported, especially in the context of decarbonization of manufacturing industry (Presidency of the Republic of Türkiye, 2023b, p. 83). Moreover, hydrogen, its derivatives and fuel cells are seen as key technologies for some of the identified priority areas like chemical industry, automotive industry and energy (Presidency of the Republic of Türkiye, 2023b, 86; 94; 107). However, it should be noted that the rehabilitation of existing coal power plants for hydrogen or ammonia production and further deployment of nuclear power plants (including Small Modular Reactors (SMRs)) are other priority areas for the energy sector (Presidency of the Republic of Türkiye, 2023b, pp. 105–106).

2.1.3 National Energy Efficiency Action Plan (2024)

In January 2024, Türkiye has published its second national energy efficiency action plan for the period of 2024–2030. Through concrete actions in seven sectors (buildings and services, industry, energy, transportation, agriculture, start-ups and digitalization), the plan aims a total of 37.1 million tons of oil equivalent (MTOE) energy savings, corresponding to 16% reduction in Türkiye's primary energy consumption between 2024–2030 (Ministry of Energy and Natural Resources, 2024a, p. 8).

In the action plan, developing hydrogen technologies is proposed as one of the actions to ensure energy efficiency in the energy sector (Ministry of Energy and Natural Resources, 2024a, p. 108). To achieve this, several fundamental steps towards establishing a hydrogen economy

were listed including reviewing the regulatory framework, investigating the wide use of hydrogen applications in hard-to-abate sectors and incentivizing domestic technology development (Ministry of Energy and Natural Resources, 2024a, p. 108).

2.1.4 Green Deal Action Plan (2021)

In 2022, the European Union (EU) was the number one export destination for Turkish goods and products, corresponding to 46% of the whole export volume (ITC, 2022). Not only for the cumulative trade value, but also for the specific product groups, whose export to the EU will be regulated under the Carbon Border Adjustment Mechanism (CBAM), the EU is again among the top export destinations for Türkiye. For example in 2022, 37% of the iron and steel products (HS 72), 25% of cement (HS 25), 50% of fertilizers (HS 31), 66% of aluminum (HS 76) and 77% of the electricity (HS 2716) exports were sent to the EU 28 (ITC, 2022).

Against this background, the EU Green Deal has become one of the priority areas for Türkiye since its first launch in 2019 and has accelerated the decarbonization attempts in Turkish industry. To ensure a timely green industrial transition compatible with the CBAM, a working group was established in 2020, comprised of bureaucrats of several ministries. Following the consultations with various private sector representatives, as the chair of the working group, Turkish Ministry of Commerce (2021) has published Green Deal Action Plan.

For CBAM, the action plan has set two major targets: (i) limiting the negative impacts CBAM may have on Turkish industry and (ii) studying the establishment of a national carbon pricing mechanism (Ministry of Commerce, 2021, p. 44). The former includes measures like creating a roadmap for reducing greenhouse gas emissions in affected industries, modelling the potential impact, updating the current industrial emission tracking system to fit the CBAM requirements, and creating support mechanisms for required emission reporting and documentation. Whereas the latter solely focuses on identifying the best fitting carbon pricing mechanism for Türkiye including potential challenges it would have on the economy. It is noteworthy, however, that Türkiye in its updated Nationally Determined Contributions (NDC) indicated that zero carbon roadmaps for steel, aluminium and cement sectors will be published soon, while even though it has been developed there was no mentioning of a forthcoming launch of carbon pricing mechanism.

While CBAM is the most relevant mechanism for Türkiye within the Green Deal, the action plan also covers targets on some other main fields including green and circular economy, green finance, secure energy supply, sustainable agriculture, sustainable smart mobility and climate change mitigation.

2.1.5 Emission Trading System (ETS)

Since 2013, Türkiye has been engaging in carbon pricing efforts through the Partnership for Market Implementation (PMI). The country has established a Monitoring, Reporting, and Verification (MRV) system that includes most installations in the energy and industry sectors. The legal framework for this system began with the "By-law on Monitoring of Greenhouse Gas Emissions" issued in 2012 and revised in 2014. It was supplemented by the "Communiqué on Monitoring and Reporting of GHG Emissions" in 2014 and the "Communiqué on Verification of Greenhouse Gas Emissions Reports and Accreditation of Verification Bodies" in 2017, both

of which were updated in 2021 and 2022. This by-law aligns with the EU Emissions Trading System (EU-ETS), excluding emissions trading, free allowance allocation, and carbon capture and storage (DoCC, 2024, p. 3).

The Twelfth Development Plan mentions that a national emission trading system (ETS) compatible with the EU ETS will be implemented (Presidency of the Republic of Türkiye, 2023b, p. 63). The Medium Term Program for 2024-2026 aims at the completion of the ETS within its term (Presidency of the Republic of Türkiye, 2023a, p. 32).

During the COP28, Directorate of Climate Change (DoCC) has announced that a pilot ETS is going to be launched in October 2024 along with the publication of National Allocation Plan (ICAP, n.d.). The ETS will be a part of the Turkish Climate Law, which is currently being drafted.

2.2 Quality of policy formulation

It can be said that the pace of setting decarbonization targets and preparing required regulatory framework have been accelerated especially after the launch of the EU Green Deal in 2019 and the ratification of Paris Agreement in 2021. Prior to those, Türkiye has also enacted laws like Energy Efficiency Law in 2007, the by-law on monitoring of greenhouse gas emissions in 2014 and the by-law on strategic environmental assessment in 2017 (Republic of Türkiye, 2023, p. 4). Additionally, to support the general strategies, specific roadmaps to enable sectoral transformation are either published or are being prepared. Those include National Transport and Logistics Master Plan (2021), emission intensive industries, smart mobility, green growth technologies, and a zero carbon roadmap for steel, aluminium and cement (Republic of Türkiye, 2023, p. 5).

However, even though this gives the impression that the governmental policies and strategies follow a coherent agenda, some details hidden in those documents reveal contradictory targets. For example, in its updated NDC, Türkiye announced that 2038 will be the emission peak year and pledged only to reduce its GHG emission growth rate by reaching 695 Mt CO₂ equivalent (eq.) by 2030 instead of 1175 Mt CO₂eq. in a business as usual scenario (Republic of Türkiye, 2023, 2; 30). In 2021, total GHG emissions were 564.4 Mt CO₂eq., indicating an increase in emissions by almost 20% until 2030 and not reducing them in absolute terms from today onwards (TÜİK, 2023a). SHURA's analysis shows that to reach net zero by 2053, total carbon emissions should peak in 2025 and decline by 37.2% in 2035 compared to 2025 (SHURA, 2023, p. 10). Climate Action Tracker, an independent scientific project, rates Türkiye's current policies as critically insufficient and notes that if all countries were to follow Türkiye's approach, warming would exceed 4°C (CAT, 2023).

Similarly, as explained above, National Energy Plan foresees around 10% increase in total installed capacity of coal power plants in the coming decade (Table 1). Türkiye spends almost 16% of its GDP to either explicitly or implicitly subsidize fossil fuels (IMF, 2021, p. 38) and continues incentivizing construction of new coal power plants (WWF & SEFIA, 2022, p. 10). When we consider, however, that Türkiye has never made a commitment to phase out coal, will soon publish a roadmap for CCU technologies and gives special emphasis on CCU in its hydrogen strategy, it clearly and coherently signals continuing use of coal. All these, however, just do not match with the net zero target by 2053.

In addition to coherency, strategies and plans also lack explicitness as they often list only vague and ambiguous actions to reach ambitious targets. Even though challenges and needs are defined often accurately, an explicit roadmap to reach them is missing. For example, in the Hydrogen Technologies Strategies and Roadmap, formulations like “opportunities will be explored”, “support will be provided”, “fuel cells will be promoted” or “domestic and national electrolysers will be developed” are common among the proposed solutions. Without defining which public body is responsible for that specific solution, how their timeline look like, who the potential collaboration partners are and which concrete milestones should be reached along that timeline, those formulations can be read at best as wishes.

3 Stakeholders Impacting the GH2 Economy

The market ramp up of green hydrogen in Türkiye is mostly driven by the private sector. Renewable energy generating firms explore diversifying in green hydrogen production and the firms in heavy industry look for ways to decarbonize their production cycles due to CBAM. Therefore, it can be said that the domestic market in Türkiye has already a well-established capacity to become active in every possible stage of the green hydrogen value chain. Similar to many countries, this potential is very much dependent on regulatory clarity both at the national and international level.

Government, ministries and public sector institutions

Ministry of Energy and Natural Resources is the main public body who shapes and implements the hydrogen agenda at the government level. In 2020, the ministry had initiated the preparation process of the Hydrogen Technologies Strategies and Roadmap with a call for stakeholders from different fields to collectively shape the hydrogen agenda in Türkiye. Based on the results of this process, two public research institutes, the **Scientific and Technological Research Council of Türkiye Marmara Research Center (TÜBİTAK MAM)** and **Turkish Energy, Nuclear and Mineral Research Agency (TENMAK)** worked collaboratively on the strategy. While both are working on developing hydrogen technologies, the former is conducting hydrogen research, especially on storage, for the last 20 years. Moreover, both research institutes also provide funding through various support programs to external research projects.

Ministry of Industry and Technology is another ministry which is involved in shaping the hydrogen economy in Türkiye, as TÜBİTAK functions under the mandate of this ministry. Moreover, development agencies that work for local economic, social and industrial development in 26 regions of Türkiye are also coordinated by the Ministry of Industry and Technology.

Among 26 development agencies, the pioneer ones in establishing a regional hydrogen economy in Türkiye are **South Marmara Development Agency (GMKA)** and **İzmir Development Agency (İZKA)**. Together with partners from private sector, industry, international cooperation and other public institutes, the former has initiated a hydrogen valley project, called HYSouth-Marmara, in the South Marmara region. The Project consortium consists of 15 partners and has in total €38 million budget, 8 million of which was received as part of the Horizon Europe Programme (GMKA, 2023). Apart from establishing a local hydrogen ecosystem, the project also includes the development of an electrolyser at megawatt scale (GMKA, 2023). İZKA, on the other hand, works to stimulate the hydrogen ecosystem in its operational territory by supporting innovative green hydrogen production technologies (Çağatay, 2022).

To support and operate the transmissions and distribution of hydrogen within the existing national pipeline network, **BOTAŞ Petroleum Pipeline Corporation** runs assessments. BOTAŞ is a state-owned enterprise for oil and natural gas pipelines and trading and currently develops an internal hydrogen strategy. They also assess the possibility of storing hydrogen in their existing salt caverns that is normally used to store natural gas (Doğan, 2022). Once the regular framework is set and the hydrogen is transported via pipelines within the country, the **Energy Market Regulatory Authority (EPDK)** will be regulatory body for this as well. However, the required regulations are not yet in place.

Private sector

Both from the upstream and downstream sectors, there are many private firms that are interested in engaging in the unfolding hydrogen market. For hydrogen production, mostly firms who already operate in renewable energy generation seek ways to engage in either local or international market, with the aim of diversification. Additionally, as it is also very much promoted and encouraged by the government, several firms work on developing electrolyser technology. Among the pioneers is **ASPİLSAN**, a battery developer majorly owned by the Turkish Armed Forces Foundation, works on developing a domestic electrolyzer as part of the HYSouth-Marmara hydrogen valley project. Also **TEKSİS**, a technology developer firm on hydrogen production systems and fuel cells, offers hydrogen production solution ranging from 1 kW to 4 MW.

For downstream, Türkiye has various industries and other sectors where hydrogen can be utilized. Moreover, due to the CBAM as explained above, many firms operating in different branches of heavy industry like iron and steel, cement, glass, ceramic, chemical and oil refinery are seeking ways to decarbonize their production cycles and green hydrogen offers great potential there. Some of these firms have already developed a roadmap on how to transition to hydrogen as an energy carrier and the others are looking for ways to eliminate e.g. knowledge gaps and other uncertainties hindering them from proceeding.

Especially in eliminating knowledge gaps and raising awareness among their members, sectoral associations play a key role in Türkiye. For example, the **Turkish Cement Manufacturers' Association (TÜRKÇİMENTO)** organizes webinars and workshops to bring experts and academicians from who work on hydrogen technologies together with the cement producers. Similarly the **Turkish Wind Energy Association (TÜREB)** not only communicates in national and international arenas the potential of Turkish wind energy sector in producing green hydrogen, but also raise awareness among their members on diversifying in green hydrogen production.

On mobility, there are also steps taken both in technology development and application. A pioneer in mobility is **KARSAN**, a domestic bus manufacturer, who has developed and produces a fuel cell bus.

For many, however, regulatory, economic and technical uncertainties both in national and international markets pose the greatest challenge and hence hinder them taking concrete steps. Engaging in hydrogen valley projects like the one mentioned above means that these uncertainties are minimized, as it often provides a closed ecosystem where demand, supply and the transportation in between are predetermined.

Universities

Researchers and academicians at the Turkish universities are another key component of the hydrogen research ecosystem in Türkiye. Faculties and research centers of different disciplines like engineering and chemistry conduct research and develop products either within their own teams or in collaboration with private sector.

Some important ones are the Turhan Nejat Veziroğlu Clean Energy Research Center at the **Niğde Ömer Halis Demir University**, the H₂FC Hydrogen Energy Research Group at the **Erciyes University**, the Energy Systems Engineering Department at the **Atılım University** and the Chemical Engineering Department at the **Middle East Technical University**. As the hydrogen demand and awareness grow in the country, so does the research interest to hydrogen technologies. Therefore, the number of hydrogen research centres at the Turkish universities also increases. A recent addition to those was the Hydrogen Technologies Centre at the **Koç**

University which has been founded in the first half of 2024. The research in those departments and centers include R&D on hydrogen production and fuel cell technologies as well application and demonstration projects. Products and technologies developed at the universities generally reach technology readiness levels (TRL) of 2 or 4. To develop a product further and commercialize it, Technology Transfer Offices (TTO) at the universities act as bridges between university research and private sector.

International actors

Among the international energy partnerships that Türkiye has built so far, the ones with Germany are particularly important as they almost solely focus on green energy transition including hydrogen. The **Turkish-German Energy Partnership** launched in 2012 supports the exchange of knowledge between diverse stakeholders from both countries to facilitate transformation of energy systems. The Partnership has five thematic working groups including renewable energy, energy efficiency, energy infrastructure and sector coupling, regulation of electricity and gas markets and flexibility of existing thermal power plants. Also, as the central platform for dialogue, every year the **Turkish-German Energy Forum** is held where the outcomes of working groups are discussed with wider stakeholders. In 2022, the Energy Ministers of both countries signed a joint declaration of intent (JDOI) during the Forum to deepen the cooperation in green hydrogen (BMWK, 2022, p. 55). The **German Energy Agency (dena)** is the main facilitator of the partnership for Germany.

Additionally, the Türkiye office of the **German Development Cooperation (GIZ)** is also very active in supporting the hydrogen market ramp-up in Türkiye. Unlike dena and the Energy Partnership, GIZ promotes and supports concrete pilot projects through programs like H2Uppp. Similarly, the **German-Turkish Chamber of Industry and Commerce (AHK Türkiye)** brings stakeholders from business together and facilitates collaborative green hydrogen projects in Türkiye.

4 What does distinguish Türkiye?

As documented in the Hydrogen Technologies Strategy and Roadmap, Türkiye is dedicated to become more than a hydrogen producer in the global market. Technology development and deployment of green hydrogen to decarbonize its own economy are among the top priorities of Türkiye. To achieve these, advantages Türkiye has are not only limited to its strategic geographic location or its diverse and rich renewable energy endowments. In this section, natural, physical and human capital, research and innovation ecosystem and the local hydrogen demand Türkiye has are discussed as factors distinguishing Türkiye from other potential green hydrogen producers of the global market. To have a realistic discussion, the analysis of these factors also includes certain challenges as indicated either by publicly available data or by the experts.

4.1 Natural, physical and human capital

4.1.1 Energy resources

Energy production

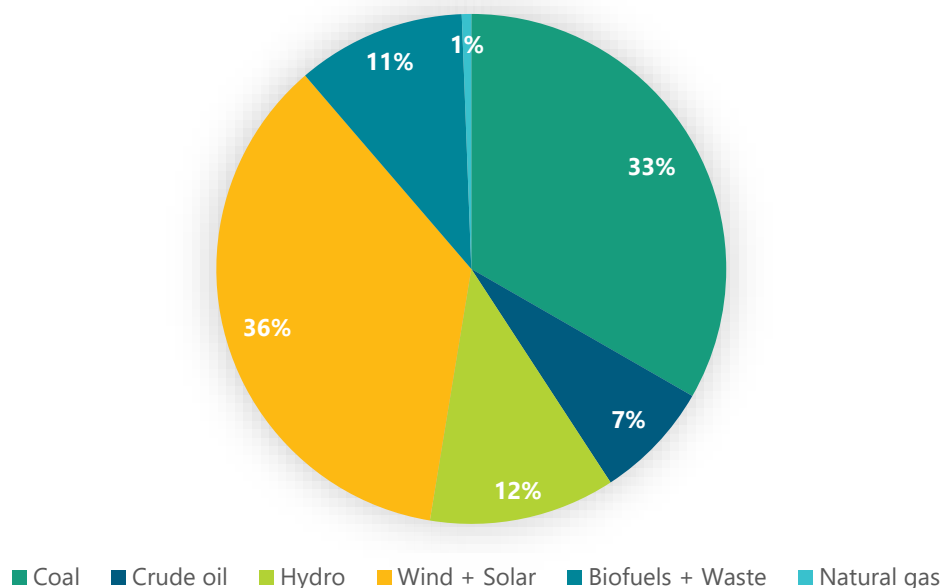


Figure 2. Domestic energy production in 2022 (IEA, 2024d)

The distribution of domestic energy generation in Türkiye in 2022 reflects a significant shift towards renewable energy sources, particularly wind and solar, coupled with a diversification of the energy mix. Despite this positive trend in renewables, with 33% in 2022 coal remains to be a major energy source for the Turkish economy. In the same year, crude oil contributed a relatively small portion (7%) to Türkiye's energy generation. While crude oil remains essential for certain sectors such as transportation and industrial processes, its share in the energy mix is gradually declining.

Hydroelectric power (12%) plays a significant role in Türkiye's energy generation, pointing out the success of water management policies implemented for decades despite water scarcity in the country. The steady share of hydro in the energy mix underscores Türkiye's continued investment in hydroelectric power infrastructure and utilization of its natural resources.

The most notable aspect of Türkiye's energy generation in 2022 is the substantial contribution of wind and solar energy (36%), accounting for over one-third of the total. This reflects Türkiye's commitment to renewable energy development and efforts to capitalize on its geographic advantages for energy transition. Biofuels and waste (11%) also contribute a significant share to Türkiye's energy generation, providing a renewable alternative to fossil fuels. This sector encompasses a variety of sources, including biomass, biogas, and waste-to-energy technologies.

Combined together, renewable sources account almost for 60% of the total domestic energy production. However, focusing solely on this indicator might be misleading, as Türkiye is a net energy importer, with imports constituting up to 73.6% of total energy supplies, and more than 80% of these imports are fossil fuels (IEA, 2024d). Increasing volumes of imported energy over the course of the last two decades indicates a reliance on imported fossil fuels to meet the country's energy needs, despite efforts to diversify the energy mix and promote domestic energy production. Therefore, to have a better understanding of the entire energy system, power generation and the role coal plays are discussed separately down below.

Power generation

Despite extensive and distributed renewable energy potential of the country and increasing installed renewable energy capacities, fossil fuels remain to be the major power source of Türkiye. Figure 3 below represents the historical trend in power generation by source.

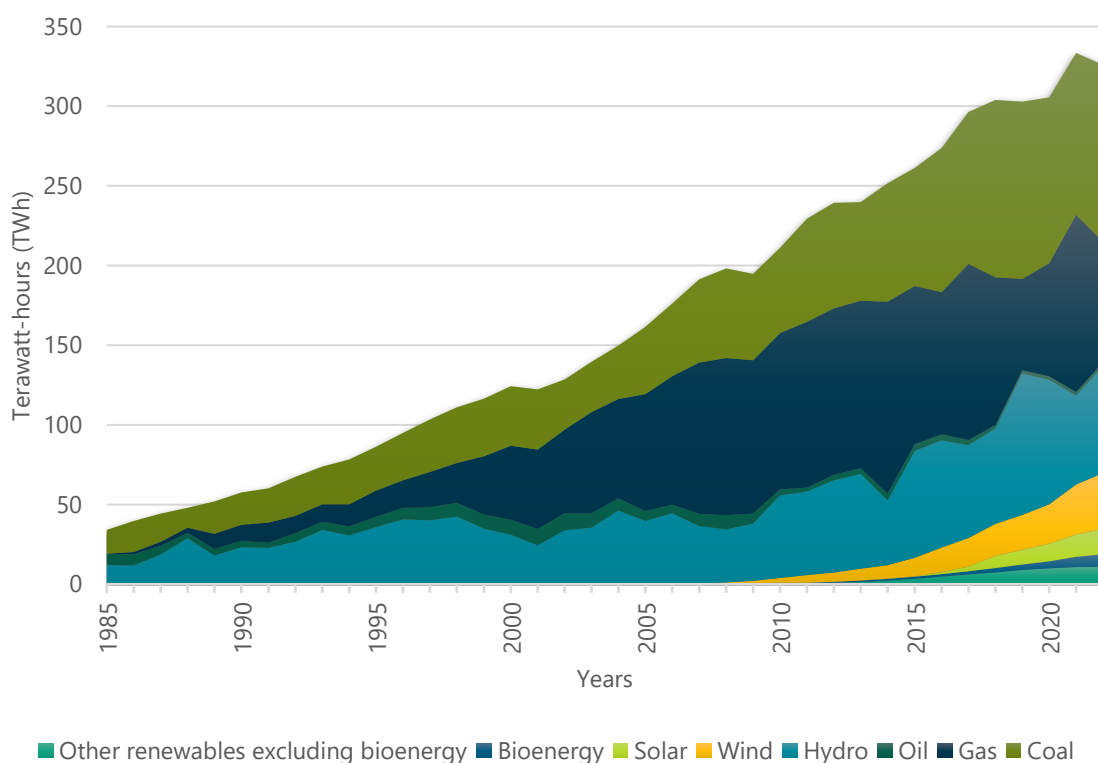


Figure 3. Domestic power generation by source, 1985-2022 (IEA, 2024b)

Unlike the energy mix discussed above, the dependence on fossil fuels, especially on coal, for power generation grows in Türkiye. This means that grid electricity will continue to be unsuitable for green hydrogen production, whether as a primary power source or solely for buffering purposes.

Nevertheless, the trend in the share of electricity generated from renewable energy sources in Türkiye also demonstrates a significant and consistent increase over the years. In 2000 and 2005, renewables accounted for 25% of the electricity generation, indicating a steady baseline sustained with hydropower. As of 2010, this share had started to increase as the power generation from wind, solar, geothermal and other renewable sources have been strongly supported through various policies including purchase guarantees and special feed-in tariffs. In 2022, renewables reached their highest share yet, comprising 42% of the electricity generation in the country.

A recent study published by GIZ Türkiye examined the potential electrolyser install capacities (with load captor of 8,000 hours/year) in four selected cities (İzmir, Bandırma, Mersin and Rize). According to their analysis, these cities have 8.2, 5.1, 6.3 and 0.03 million MWh of unused renewable electricity potential, respectively (Dursun et al., 2023, p. 38). If all these available and unused potential were to power electrolyzers, then in each of these cities it would be possible to install electrolyzers with 988, 231, 734 and 434 MW capacities, respectively (Dursun et al., 2023, p. 38). That means, by utilizing the untapped renewable power in only four cities, Türkiye can reach its goal of 2GW installed electrolyser capacity by 2030.

Coal and recent natural gas explorations

In 2023, electricity generation from coal increased 4% compared to the previous year and accounted for 36% of the total generation (Gümüş, 2024, p. 7). The same year, country spent approximately \$3.7 billion USD on coal imports for electricity generation (Gümüş, 2024, p. 9). The majority of Türkiye's coal reserves consist of low-calorie lignite, a type known for high pollution levels compared to other coal varieties (HEAL, 2018, p. 6).

While coal plays a significant role in meeting energy demands, its adverse effects on public health and the environment cannot be ignored. The share of coal in Türkiye's total CO₂ emissions has reached 41% in 2022 (IEA, 2024a). Moreover, estimates suggest that expediting the phase-out of coal power by 2030 instead of in the 2050 could potentially save more than 100,000 lives (HEAL, 2022, p. 6).

Türkiye's accelerating fossil fuel use is not only limited to coal. The recent gas exploration endeavours of the country have taken a significant leap forward with the discovery of the Sakarya field in the Black Sea. This discovery, with an estimated potential of 710 billion m³ of natural gas, marks a pivotal moment in Türkiye's energy landscape and strategic goals (European Commission, 2023, p. 112).

Given the increasing importance of coal in Türkiye and the diverging government policies on the issue compared to the EU, estimates suggest that the country will be the top coal burner in Europe in 2024 (Maguire, 2024). Therefore, as discussed in Chapter 2, it is no surprise that coal is among the top energy sources that Türkiye wants to utilize for hydrogen production. In fact, during our consultations it was repeatedly emphasized that earlier versions of Türkiye's Hydrogen Technologies Strategy and Roadmap had even a stronger focus on coal, but it was later toned down (Interview 26, 2023; Interview 3, 2022). This also aligns with the fact that during the participatory meetings for the preparation of the Strategy, 85% of Turkish experts

stated it is important to support hydrogen production projects from domestic coal source (Ministry of Energy and Natural Resources, 2020, p. 5).

4.1.2 Water

To produce 1 kg of green hydrogen, electrolyzers require 9 to 11 litres of fresh water. Depending on the cooling system of electrolyzers, it might be as high as 35 litres of distilled water. If the distilled water is to be produced from seawater via desalination, then 83 litres of seawater is needed to produce 1 kg of green hydrogen (Miltrup, 2024). Nevertheless, high water requirements of green hydrogen production are assumed to play no significant role at scale (SHURA, 2021b, p. 60).

As it is seen from Figure 4 below, Türkiye is mostly an arid to semi-arid country. Unequal distribution of rainfall, climate change, growing population and increasing demand from agriculture, industry, and urbanization will likely increase the existing water stress in the country. The population is expected to reach 90 million by 2030 and hence the available water per capita per year will drop from 1350 m³ to 1240 m³ (Kibaroğlu, 2022).

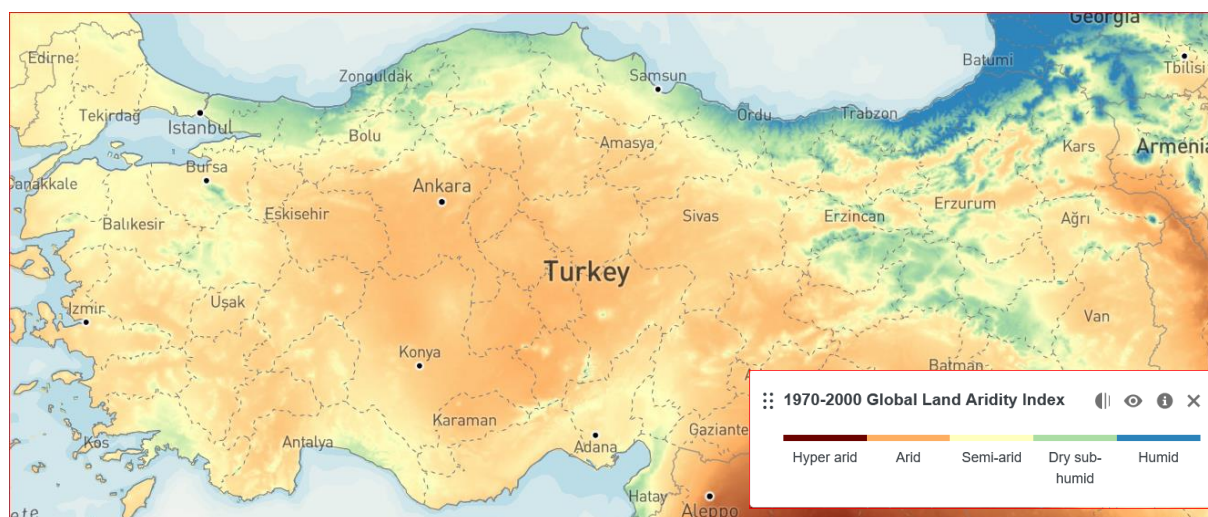


Figure 4. Land aridity index, Türkiye (Trabucco & Zomer, 2019)

As green hydrogen production scales up to meet Türkiye's energy and decarbonization goals, the demand for water could exacerbate existing water stress. Increased water demand might lead to conflicts over water usage between different sectors and further deplete already stressed freshwater resources. Moreover, a geopolitical conflict might also arise due to the transboundary rivers, if they are used for green hydrogen production (SHURA, 2021b, p. 60). Unilateral projects like dams and hydropower plants on those rivers had already caused conflicts in the past (Climate Diplomacy, n.d.).

Efficient water management, investment in water-saving technologies, and the exploration of alternative water sources, such as seawater desalination or wastewater, will be essential to ensure that green hydrogen production does not further strain Türkiye's limited water resources.

4.1.3 Built infrastructure

Pipelines

Even though Turkey has almost no oil and natural gas reserves, several pipelines go across the country due to its proximity to resource-rich neighbouring countries. These pipelines transport Iraqi and Azerbaijani crude oil as well as Azerbaijani, Iranian, and Russian natural gas, connecting these resources to the European market. Below is a representation of crude oil and natural gas pipelines crossing Türkiye.

The Trans-Anatolia Natural Gas Pipeline (TANAP) is one of the most recent pipelines that became fully operational in late 2020 and it is connected to the Trans Adriatic Pipeline (TAP) in Greece. TANAP starts at Türkiye's Georgia border and ends at the Greece border (shown in Figure 5 with thick orange line). One of the cities the pipeline passes is Balıkesir, where the HySouthMarmara hydrogen valley is also located. Therefore, in the future, Türkiye is in the position to utilise these strategic pipeline routes either by repurposing the existing pipelines to transport green hydrogen in its gaseous form or by building parallel ones suitable for hydrogen transmission.

Figure 5 also shows the natural gas transmission network which is owned and operated by BOTAŞ and reaching to some major cities. From these hubs, natural gas is then distributed to every city in Türkiye through distribution networks. In other words, Türkiye has a well-connected and modern natural gas pipeline infrastructure. However, because the pipelines are so well-connected, any blending of hydrogen into the network would mean that it is infused into the natural gas and is distributed every customer at least in that particular regional network. When safety measures are taken properly that represents normally no problem. However, since natural gas blended with hydrogen should be optional and not the obligatory product, system operators must ensure the delivery of different types to the customers who wish to receive particular gas. As there is only one distribution network reaching to every customer, it might be difficult to set the system boundaries and operate with two types of products (Interview 8, 2022). Therefore, any testing for either blending in or repurposing pipelines should be carried out in closed pilot systems.

Repurposing the existing natural gas infrastructure for hydrogen might not be limited to pipelines. As mentioned in Chapter 2 and 3, the existing underground natural gas storage units of BOTAŞ at the Tuz Lake (located below Ankara and marked with UGS in Figure 5) is being tested to store hydrogen as well (Doğan, 2022). Those are underground salt caverns and will most likely be the major storage units for Turkish hydrogen in the future.



Figure 5. Representation of crude oil and natural gas pipelines crossing Türkiye (BOTAŞ, 2023)

Ports

Ports play a vital role in Türkiye's international trade, as the country is surrounded by water bodies from north, west and south. Moreover, Türkiye has two straits (one in İstanbul and the other in Çanakkale), that constitute the only water connection between Black Sea and the Mediterranean. Therefore, especially the Port of Ambarlı in İstanbul and the Port of Gemlik in Balıkesir are two major cargo ports along the route of two straits. In addition to those, ports in Mersin, İzmir, Aliğa and İskenderun are other major ones equipped with LNG infrastructure (see Figure 5).

The Port of Aliğa in İzmir is surrounded by various heavy manufacturing industries like petrochemical, steel and wind turbine manufacturing. To complete the local ecosystem and to ease the connectedness of the local and international manufacturers with the global markets, there is also Izmir Free Zone located approximately 26 km to the Port of Aliğa. However, due to limited available land and continuously growing industries, the Port of Aliğa is slowly reaching its natural limits and will soon be unable to expand any further. Therefore, especially to facilitate the growth and export opportunities of wind turbine manufacturers of the region, İzmir Çandarlı Port together with İzmir Clean Energy Specialized Organized Industrial Zone and Bergama Free Zone are developed and they will soon be operational (IZKA, 2022, p. 72).

The fact that such well-developed logistical infrastructure and many other suitable conditions (e.g. renewable energy potential, potential industrial off-takers, international ports, raw materials, experiences and know-how gained through wind turbine industry) coexist, makes the İzmir region a very good candidate for a second hydrogen valley of Türkiye. Even though at the time of writing this report there is no such conceptualized project to our knowledge, there are further supporting evidence that, in the future, Çandarlı Port will be facilitating the hydrogen economy in Izmir region. As the port is designed, in addition to supporting the export of wind turbine components, it will also facilitate the production of maritime fuel. (Interview 31, 2024). Therefore, particularly the Çandarlı Port but also other ports in Türkiye together with their hinterland already offer great opportunities for hydrogen market to thrive.

Electricity grid

In Türkiye, there is one central and state-owned transmission system operator (Turkish Electricity Transmission Corporation – TEİAŞ). The distribution system had been divided into 21 regions and each region was commissioned to a private electricity distributor.

According to the projections of TEİAŞ, the installed domestic power generation capacity of 107.8 GW in 2023 will increase to 184.3 GW in 2028 and to 210.8 GW in 2033 (TEİAŞ, 2024, p. 2). That means an additional 76.5 GW installed capacity until 2028 is expected in the country. In the same projection, the total available connection capacities for conventional power plants (e.g. coal, natural gas, hydropower and geothermal) are estimated to be 1.5 GW for 2024-2028 period¹ (TEİAŞ, 2024). If this estimation is realistic, than only 1.5 GW connection capacity will be accommodated to the conventional power plants, while the remaining 75 GW must be covered by wind and solar power plants. Consulted experts estimate that the system is able to accommodate an additional of 27-30 GW of renewable energy (wind and solar) in the coming

¹ No estimation for available connection capacities for non-conventional power plants (e.g. wind and solar) were shared by TEİAŞ.

years (Interview 20, 2023). If this expert estimation is considered to be correct, then the available grid capacity should be at least doubled until 2028.

It should be noted, however, that green hydrogen in Türkiye is not expected to rely on grid electricity, as the grid will not achieve 100% carbon neutrality at least until 2053. Nevertheless, the projection of adding an additional 75 GW of wind and solar power to the grid by 2028 presents a significant growth opportunity for the Turkish wind and solar industries, independent of international demand. Additionally, the demand created by the target of 2 GW of electrolyser capacity by 2030 should also be considered.

4.1.4 Human and social capital

Even though, in 2023, the share of elderly (65+) has passed 10% mark for the first time in history (TÜİK, 2024b), Türkiye has still the advantage of having a young population in developing a domestic green hydrogen market. Similarly, the labour force participation rate of young population (15-24) has been rising, reaching 45% in 2023 (TÜİK, 2023d). Engagement in higher education is vital for developing young adults' skills, enabling them to make meaningful contributions to society (OECD, 2023a, p. 214). In Türkiye, the education level of overall population improves constantly. As seen in the Figure 6 below, the shares of higher education and upper secondary school graduates have grown in the last decade.

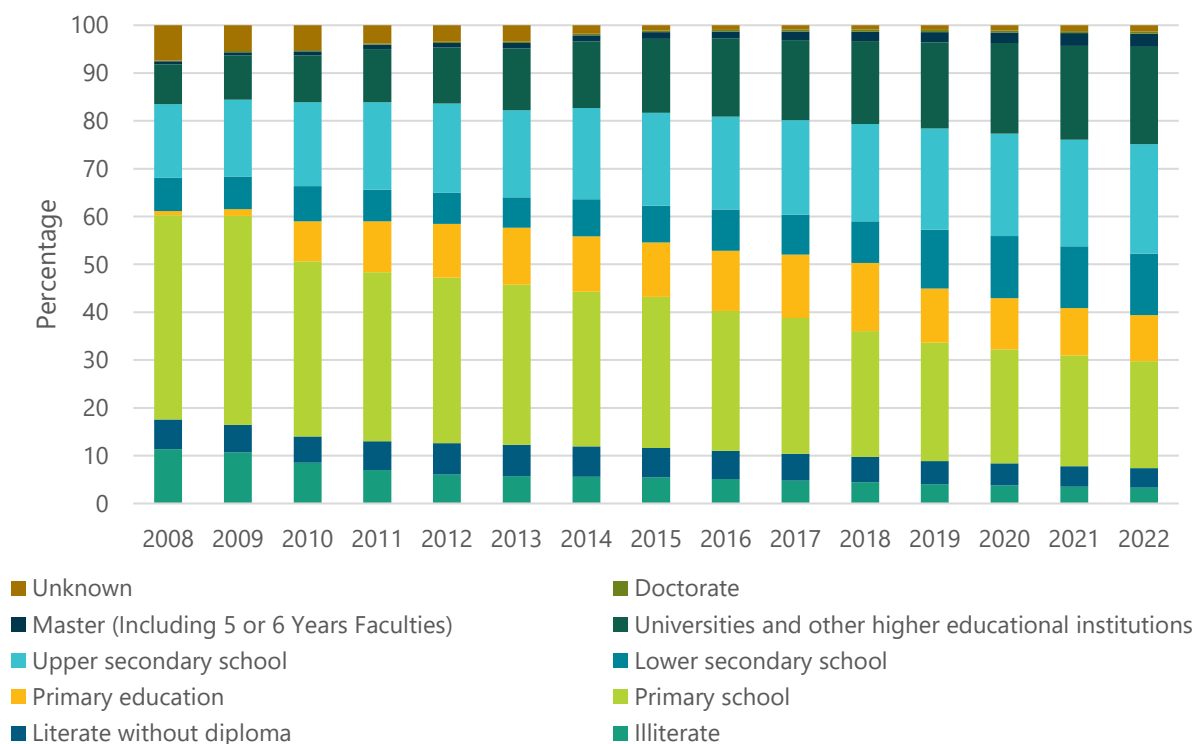


Figure 6. Distribution of population by the level of education completed in Türkiye (TÜİK, 2023e)

As almost every step along the green hydrogen value chain requires the collaboration of different technical and scientific fields, graduates in science, technology, engineering (including ICT fields) and mathematics (STEM) in a country are particularly important in ramping up the domestic market. Figure 7 below shows the share of new tertiary graduates in STEM in OECD

countries. In 2021, this share was 40% in Türkiye, ranking the country among the lowest ones within the OECD.

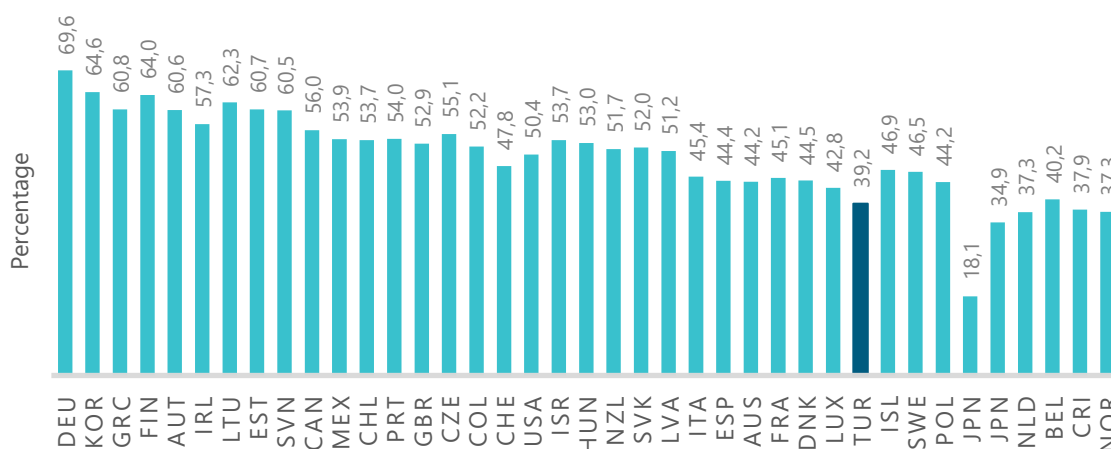


Figure 7. Share of STEM tertiary graduates in OECD countries in 2021 (OECD, 2021)

In the domestic economy, however, the graduates of STEM and other relevant fields do engage in the labour market extensively, creating economic value through their qualified education. The Figure 8 below represents the labour participation rate among all higher education graduates (the black bar in the figure) as well as several selected higher education field. While the average participation rate is 77% for all higher education graduates, engineering graduates has the highest share of labour force participation with 87% (TÜİK, 2023c).

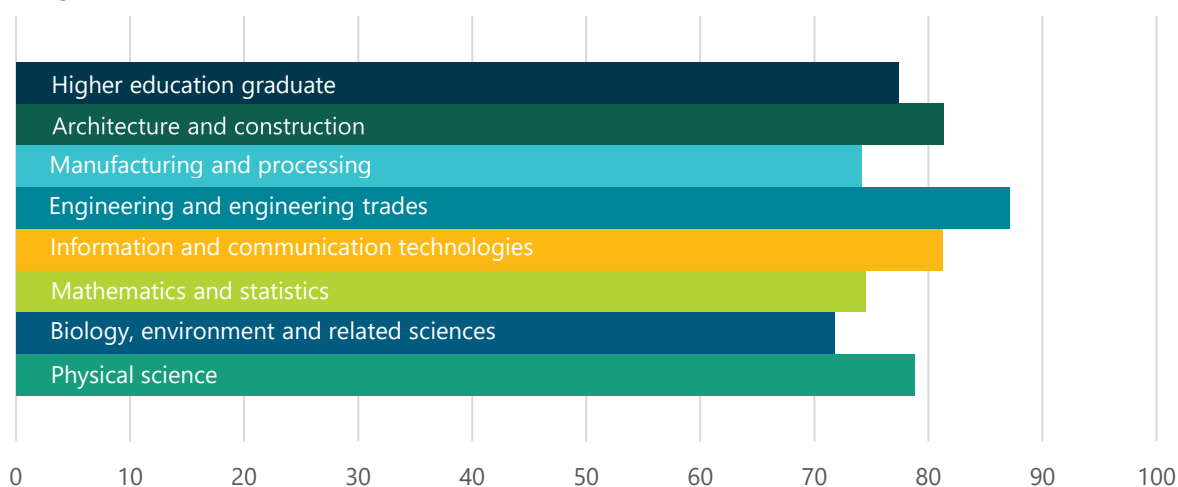


Figure 8. Labour force participation rate of higher education graduates and some selected subjects in 2023 (TÜİK, 2023c)

Despite the fact that youth unemployment has been decreasing over the course of last five years (17% in 2023) (TÜİK, 2023d), OECD comparison reveals again another rather negative picture for Türkiye. Below the Figure 9 shows that Türkiye has the second highest share of young people who are neither in employment nor in formal education or training (NEET) among 18-24 year-old population, with reaching as high as 33% (OECD, 2023a). That means one of every three young people between 18-24 ages is engaged neither in working nor in education or is active only in the informal economy. On the other hand, this also indicates an unused workforce potential, that can be trained or directly employed for either qualified or low-skill positions in the green hydrogen market.

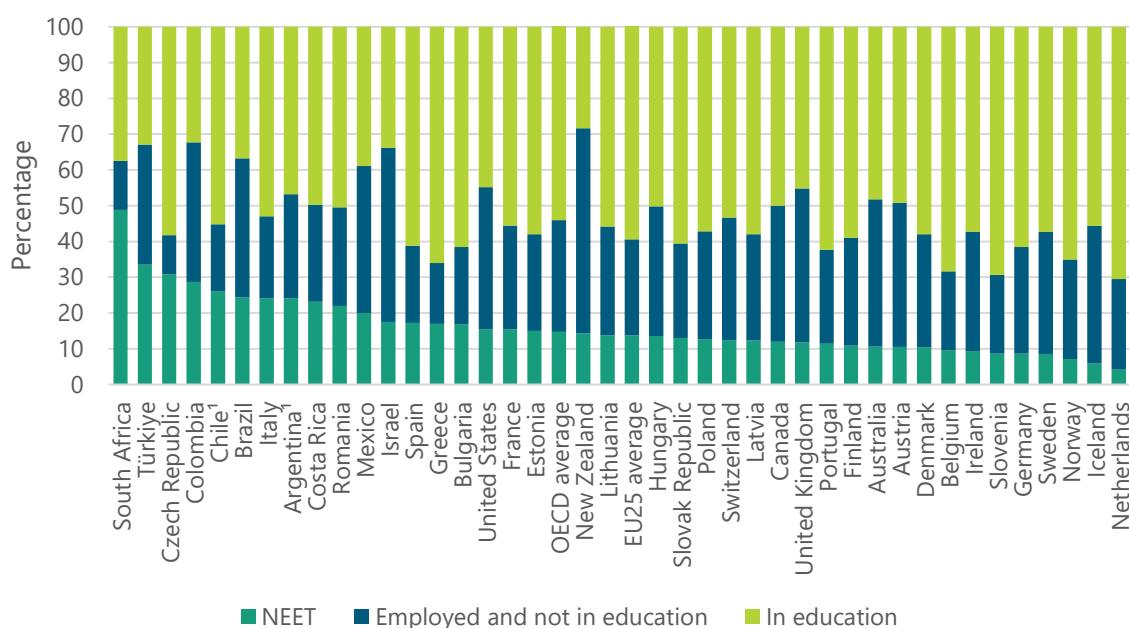


Figure 9. Distribution of 18-24 year-olds by education and work status in OECD countries (OECD, 2023a, p. 59)

Given that higher education has been free in Türkiye since 2012, university enrolment rates may have increased compared to the period before 2012 when a moderate tuition fee was required. The increasing shares of university and master graduates since 2014 (see Figure 6) indicate this tendency. However, despite the 9.8% unemployment rate among higher education graduates in 2023, which shows a continuous decreasing trend, it is less likely that young people aged 18-24 who are currently in education (see Figure 9) will end up as NEET in the near future. Therefore, it can be argued that free education has increased access to higher education, making it easier for young adults to find jobs. This, however, does not provide information on the quality of higher education. Figure 9 suggests that it is primarily the graduates of secondary and vocational education who are more likely to end up unemployed or as NEET. Therefore, it could politically and economically make sense to target these groups and improve their capacities in participating labour market. Channelling them in the unfolding green hydrogen market can bring win-win opportunities.

4.2 Research and innovation ecosystem

As explained in Chapter 2, technology development for hydrogen production, storage, distribution and utilization is among the top priorities targeted by the Hydrogen Technologies Strategy and Roadmap. Hence, the existing research and development (R&D) ecosystem in the country will play a key role in realizing this target.

The R&D ecosystem in Türkiye is already a well-established one, where the government plays a central role in shaping national science technology and innovation (STI) agenda and strategy as well as allocating the limited public funds for selected STI fields. Together with the change of government structure from parliamentary to the presidential one in 2018, how the R&D system and its institutions are governed have also changed. In the new presidential system, the Council of Presidency Science, Technology and Innovation Policies, which is directly connected

to the President, has become the central body that is responsible for the coordination of all STI activities (TTGV, 2020, p. 31). Representatives from public bodies, industry, academia and NGOs composes the Council and hence may take part in policy-making (TTGV, 2020, p. 33). Figure 10 below represents the current STI system and its actors in Türkiye.

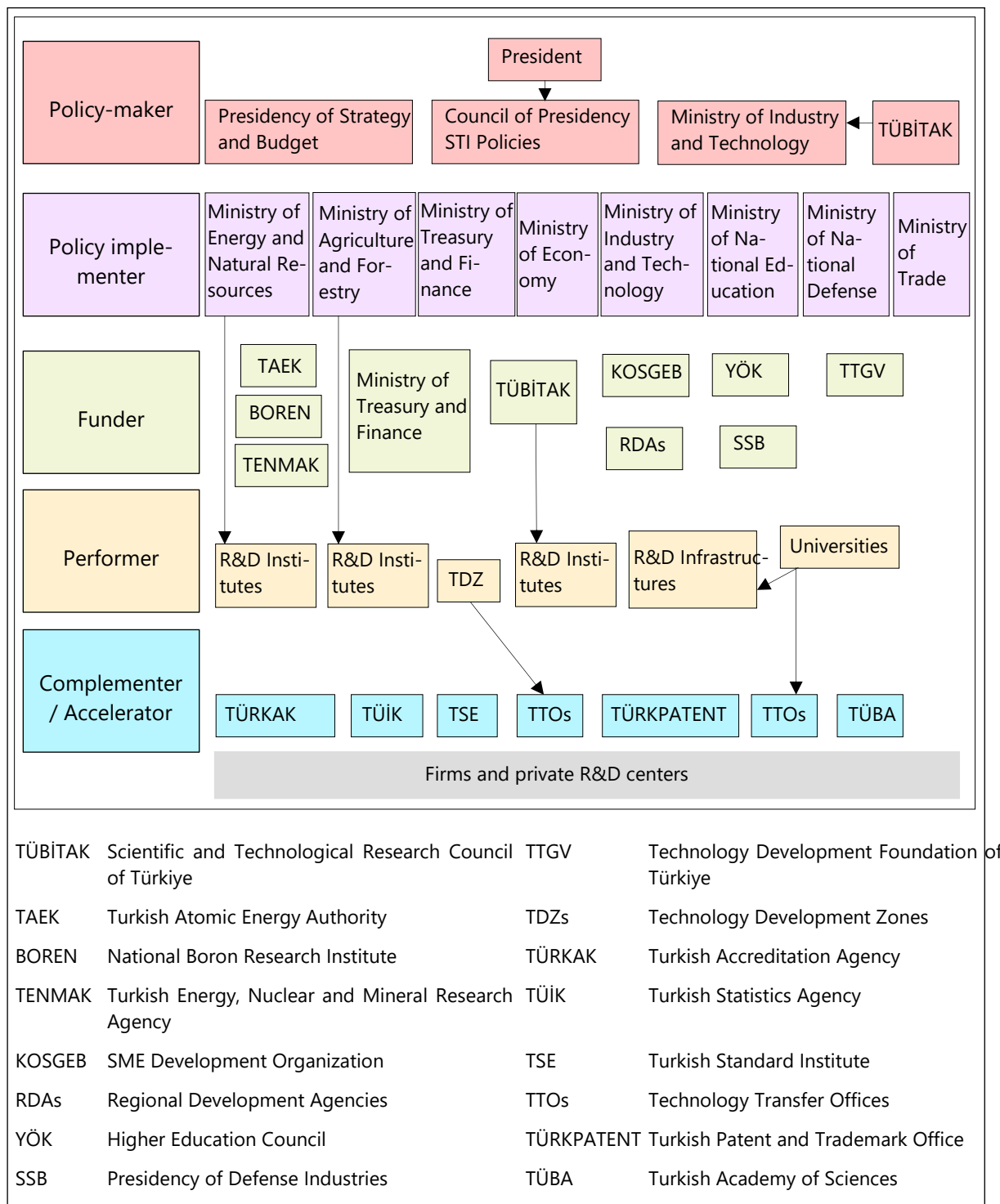


Figure 10. Actors of Türkiye’s STI system (modified and reproduced from TTGV (2020, p. 33))
As shown in Figure 10, STI policy-making is almost exclusive to the president and his government, apart from the members constituting the Council, who are also appointed by the presi-

dent himself. Once the strategies are set and the policies are approved by the president, relevant ministries and their respective public bodies take action to implement them by providing funding or performing the R&D directly. These two steps are also conducted by private firms and R&D centres. Additionally, they also support the system by providing complementary and acceleratory activities like commercialization (TTGV, 2020, p. 34).

The last national strategy document shared by the Council was for the period of 2011-2016. However, the 2024-2025 priority areas for R&D and innovation announced by TÜBİTAK represent the current direction the STI policy in Türkiye is heading to. The selected priority areas are listed under 4 main categories: (i) Green growth and Green Deal, (ii) natural disasters, (iii) digital technologies and (iv) innovative technologies to support the priority areas under the Twelfth Development Plan including health, food, automotive and defence industries (TÜBİTAK, 2024, p. 3).

The first category of these priority areas is the one where hydrogen technologies should be most relevant to. To better identify and accelerate the development and integration of technologies needed to increase green industrial production, Green Growth Technology Roadmap was published by TÜBİTAK in 2023. The roadmap focuses on iron and steel, fertilizer, aluminium, chemicals, plastic and cement industries by identifying technological needs and respective solutions for each of these industries. For almost all these sectors, both hydrogen and CCU technologies are identified to support the green growth as well as the compliance with the European Green Deal (TÜBİTAK, 2023, p. 43). The roadmap is particularly important and it is different from other policy documents, as it concretely depicts how the technology development in those sectors will be supported. It includes a special call (Industry Innovation Network Mechanism (SAYEM)) for co-creating suitable solutions for specific cases, and the development of product-specific roadmaps to commercialize green growth-focused technologies and products (TÜBİTAK, 2023, p. 44).

Another cornerstone in the national R&D policy and practice is boron mineral. Türkiye holds 73% of world boron reserves (BOREN, n.d.-b) and uses this mineral in diverse manufacturing industries like glass, ceramic and chemicals (Sokmen & Buyukakinci, 2018, p. 1160). However, given boron's numerous advantages over other technologies, its most significant utility lies in energy and hydrogen storage. Sodium borohydride (NaBH₄) is the widely used form of boron for hydrogen storage, as it is non-flammable, non-explosive, odourless, can be stored in room temperature and requires minimal space in vehicles (BOREN, n.d.-a). Therefore, Türkiye is very keen on utilizing its immense boron reserves and developing technologies for wider application of this mineral in hydrogen storage.

The main public research institute on boron is BOREN, which is one of the five separate thematic research institutes operating under TENMAK. While BOREN conducts R&D in various application areas, TÜBİTAK MAM and the hydrogen research team there specifically focus on developing different hydrogen storage applications of sodium borohydride.

R&D in private sector also reflects the STI policy and priorities set by the government. As of 2024, Türkiye has already several start-ups or more established firms with innovative hydrogen technologies that are supported by the incubation mechanisms to make their product commercially competitive for the unfolding hydrogen market. Incubation and acceleration mechanisms provide financial and visibility support that are mostly delivered by the regional and local development agencies, TDZs and TTOs (see Figure 10). For example, Cyclizm was one of the start-ups who received support from the Accelerate Izmir programme of Izmir Networking and

Innovation Centre (NIC). Cyclizm offers a cloud-based platform that increases the efficiency of green hydrogen investments by up to 50% and reduces initial investment and operation costs by up to 20% with artificial intelligence-supported optimization (Izmir NIC, n.d.). Also HYDRO-LYX Energy was among other firms that was supported by the Izmir NIC. Among other technologies, they developed a drone that can both fly and ride on the ground, offering an innovative solution for unmanned delivery purposes for small packages and it is run with fuel cells (Hydrolyx Energy, n.d.).

4.2.1 Implementing capacities

Despite announced STI policies that would support the establishment of a hydrogen economy in Türkiye, there are certain factors hindering wide and accelerated implementation of these.

First of all, economic limitations play an important role. According to the Turkish Statistical Institute (TÜİK), annual increase in consumer price index (also known as inflation rate) in March 2024 was 68.5% (TÜİK, 2024a), while ENAGrup, a group of independent economists and scholars, calculated the inflation rate for the same period as 124.6% (ENAGrup, 2024). Even if the official value from TÜİK is taken into consideration, it can be noted that an annual inflation rate approaching to 70% creates a very volatile and unforeseeable economic environment, in which R&D investments are among the first ones private firms cut down.

A similar effect can also be observed in public funding. As Figure 11 shows below, the continuous trend in increasing share of gross domestic expenditure on R&D (GERD) in GDP was disrupted in 2022, falling to 1.32%. This also has a negative impact on reaching high levels of TRL in hydrogen technologies. Even though TENMAK identifies its role as product development up to TRL 6 at maximum (Bayram, 2023), many products with cutting edge technologies developed by public research institutes remain at the prototype level due to limited funding (Interview 3, 2022). Economic factors also limit the industry to take up developed technologies and improve their TRLs. Hence they rarely find their ways from labs to commercial markets.

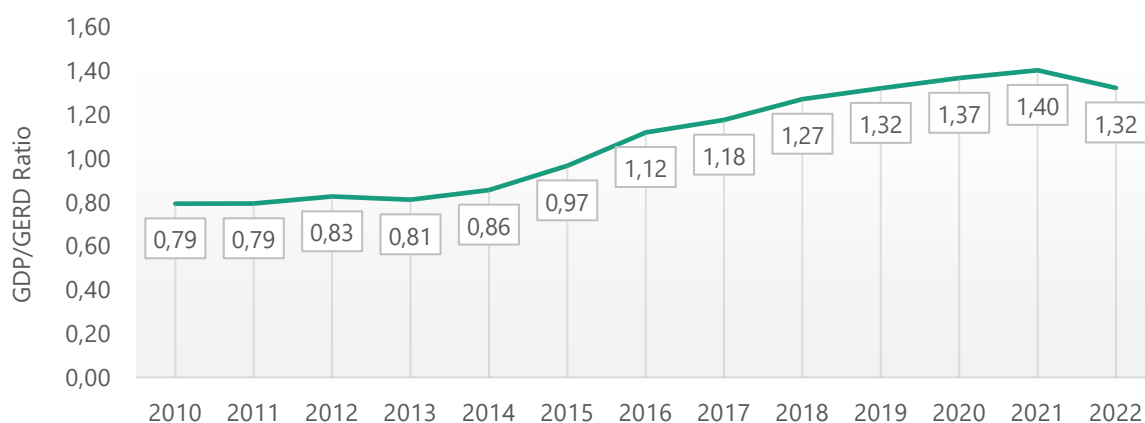


Figure 11. Evolution of gross domestic expenditure on R&D (GERD) in Türkiye as a percentage of GDP (TÜİK, 2023g)

The second factor is the fact that, despite increasing trends, the share of high technology products in Turkish manufacturing sector remains low. Even though half of the total R&D expenditure in Türkiye goes to high technology, (see Figure 12 below), high technology products still constitute only a small fraction of the manufacturing industry. For example, in 2022, the share

of high technology goods within all exported manufactured products was 3.6%, ranking Türkiye last among all OECD members, whose average is 18.2% (World Bank, 2024a). Despite being comparatively low, 3.6% share was a historical record for Türkiye, representing a positive trend in high technology development.

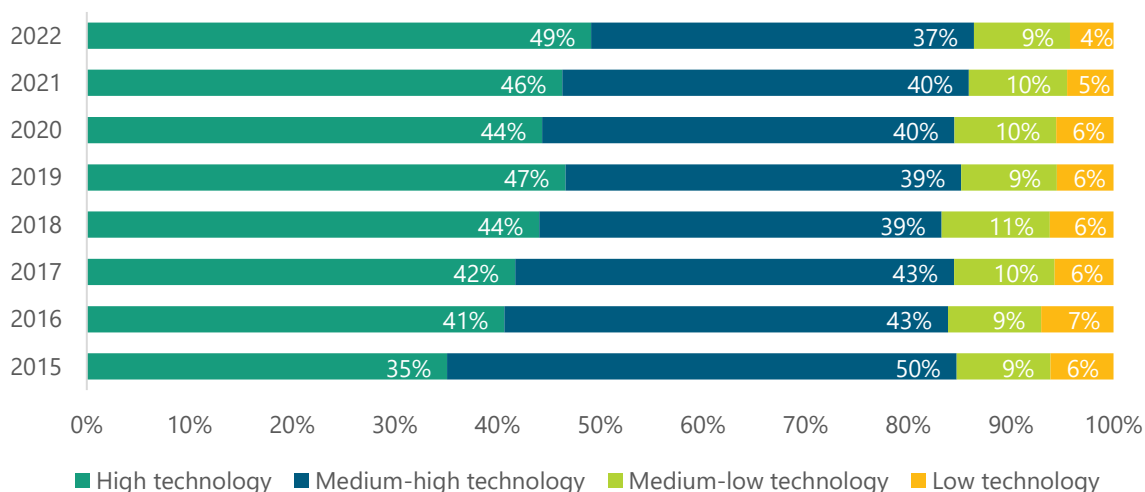


Figure 12. R&D expenditures in manufacturing industry by technology level (TÜİK, 2023f)

Among the leading high-technology sectors, defence and aerospace industries achieved the highest value-added exports in 2022 (Defence Turkey, 2024) and they were able to increase their cumulative financial turnover by 20% compared to 2021 (SASAD, 2023, p. 5). One of the main reasons of increasing economic activity and adaptation of high technology is the targeted government support to both of these sectors. Due to strategic importance of defence and aerospace industries, through various incentive mechanisms domestic private enterprises developing technology have been financially supported. Therefore, despite current low TRLs in hydrogen technologies, when a similar approach is taken, they can also contribute to the high technology production and accelerate the hydrogen market ramp-up in Türkiye. It should be, however, also noted that there are already organic ties between defence and hydrogen sectors, as hydrogen was already a part of R&D activities in the defence sector. For example, ASPİLSAN, who normally develops batteries for military vehicles, is now involved in electrolyser production. Or the research on boron mineral for energy storage was first initiated for the development of defence technologies. Hence, even without an additional support, R&D in defence sector might have spill-over effects on the development of domestic hydrogen technologies.

The last factor that could limit the implementation capacities of R&D, especially in the long-term, is the increasing brain drain from Türkiye. Emigration among qualified population and university graduates has been an issue for the last decade. However, the data on emigrants have been published only starting from 2021, making it difficult to quantitatively observe the trend since the beginning of this last exodus wave. According to the Turkish Statistical Institute (TÜİK), in 2022 around 467 thousand people have emigrated from Türkiye, indicating a 62% increase compared to 2021 (TÜİK, 2023b). Among the 467 thousand emigrated people, 42% were between 20-34 years old (TÜİK, 2023b), showing that it is mostly the young and educated professionals, who emigrates.

Due to lack of data, any analysis on the educational background of this increasing number of emigrants remains anecdotal. But it is possible to say that IT specialists and engineers, both

very relevant for the hydrogen economy work force, are some of the major groups among the emigrants. Either due to the brain drain or other factors, it can be observed that R&D in Türkiye is not among the most appealing career options for professionals. Figure 13 below shows that Türkiye ranks third to last among the OECD members in number of researchers within the labour force. The difficulty of finding educated young professionals by R&D departments was also emphasized during our onsite consultations (Interview 1, 2022).



Figure 13. Number of total researchers per thousand labour force in 2021 (OECD, 2023b)

4.2.2 Availability of funds for RDI

National level

As shown in the Figure 10 above, national research funds targeting specific STI areas are mostly distributed through major public research institutes like TENMAK and TÜBİTAK. After the launch of Hydrogen Strategy, TENMAK has started to open annual calls for research funds in hydrogen and fuel cells technologies, carbon capture utilization and storage, and energy digitalization. TÜBİTAK, on the other hand, manages a financially bigger and thematically wider funding pool through various permanent and temporary calls for researchers from universities, industry and other research institutes. These include not just specific calls for hydrogen and fuel cell technologies, but also other more general ones, where hydrogen research can also be funded, like green transformation, SAYEM (see Chapter 4.2.1) and others. For graduate and undergraduate students, scholarships and grants including research on hydrogen technologies are provided by the Higher Education Council (YÖK).

On the other hand, as of 2023, Technology Development Foundation Türkiye (TTGV) announced that they will be focusing exclusively on supporting climate technologies, including hydrogen and fuel cells. Similar to some funding options offered by TÜBİTAK, TTGV also opens calls for green transformation in the industry and targets practical applications mostly at the

pilot scale. To address diverse needs and to provide also valley of death financing,¹ TTGV has different support programs for technologies with different TRLs. Additionally, they also have programs to support private firms and businesses in planning their transition into carbon neutrality by conducting analyses, building roadmaps and facilitating financial collaborations.

Lastly, Regional Development Agencies (RDAs) also open calls for funding based on the priorities set by the Ministry of Industry and Technology for their respective regional mandates. As mentioned in Chapter 3, South Marmara (GMKA) and İzmir Development Agencies (İZKA) are the pioneer ones among the RDAs in terms of facilitating regional hydrogen economies.

International level

At the international level, various research funding mechanisms of the European Union constitute one of the major financing sources for R&D in Türkiye. Among those, Turkish researchers from universities, public and private sector mostly prefer to seek funding through Horizon Europe (previously Horizon 2020), which also gives them the chance to engage with other European research.

Clean Hydrogen Partnership, as the successor of the Fuel Cells and Hydrogen Joint Undertaking, is a major funding source pooled jointly by the European Commission, Hydrogen Europe and the Hydrogen Europe Research. The Partnership opens annual calls for proposals since 2022 and the last annual available budget amounts to €113.5 million for various topics ranging from complex projects like hydrogen valleys to individual technologies along the value chain (Clean Hydrogen Partnership, 2024). HYSouthMarmara, the first hydrogen valley project from Türkiye, received €7.4 million from the Clean Hydrogen Partnership in 2022, which was the highest EU grant received from Türkiye so far (Ufuk Avrupa, 2023).

In March 2024, World Bank announced a new Country Partnership Framework (CPF) for Türkiye for the period of 2024-2028. The new CPF will be delivering in total \$18 billion and when this is added to the current country portfolio of \$17 billion, it constitutes the third largest country program of the World Bank (World Bank, 2024c). The thematic scope of the CPF covers sustainable productivity growth, inclusive jobs and strengthened resilience against natural disasters, also shaped after the Twelfth Development Plan (see Chapter 2.4.2) of the Turkish government (World Bank, 2024c, p. 9). The former of these three includes several financing packages particularly focusing on fostering the decarbonization and green energy transformation in the Turkish private sector, accounting to the \$3.3 billion of the total budget (World Bank, 2024b). These packages include projects like Türkiye Green Industry Project, which will be targeting small and medium enterprises through KOSGEB, as well as green innovations through TÜBİTAK or Türkiye Green Export Project to support Turkish exporters in their green transition (World Bank, 2024b). These and others offer a chance to the Turkish private sector to finance their transition into green energy, also using renewable hydrogen.

¹ In innovation research, the “valley of death” describes the moment, when a technology must leave the laboratory and has to prove its feasibility at a commercial or quasi-commercial scale. Funding needs are high and often, public R&D funds will not suffice, while private funds may not yet be available due to the high levels of uncertainties.

4.3 Local hydrogen demand

A study by SHURA estimates that green hydrogen demand in Türkiye will account for 4.6 million tons of oil equivalent (Mtoe) per year by 2050, 2.1 Mtoe of which will be the industrial demand and 1.8 Mtoe is estimated to be required by the road freight transport (SHURA, 2021a, p. 7).

In 2022, Türkiye's total energy consumption was 120 Mtoe per year (Ministry of Energy and Natural Resources, 2024b). Figure 14 below represents the shares of different sectors within this consumption. Industry has the biggest energy consumption with 31%, followed by the transportation with 26%.

Within the industrial sector, 30% of the energy consumption was covered by electricity, whereas natural gas accounted for 24% (Ministry of Energy and Natural Resources, 2024b). Despite overall relatively high electrification in industry, the picture changes in mineral (cement, ceramic and glass) industry. For example, in cement industry, the majority of the required energy comes from petroleum coke (40%) and coal and lignite (35%), whereas electricity only accounts for 12% (Ministry of Energy and Natural Resources, 2024b). In metal industry, on the other hand, the share of electricity within the total final energy consumption is as high as that of coke (31% each) (Ministry of Energy and Natural Resources, 2024b). The high shares of coal, natural gas, and petroleum products in the energy supply reveal the industry's dependence on fossil fuels and indicate that there is still a long way to go to achieve decarbonization. Yet, as discussed above, decarbonization should be achieved as fast as possible due to soon to be implemented CBAM framework.

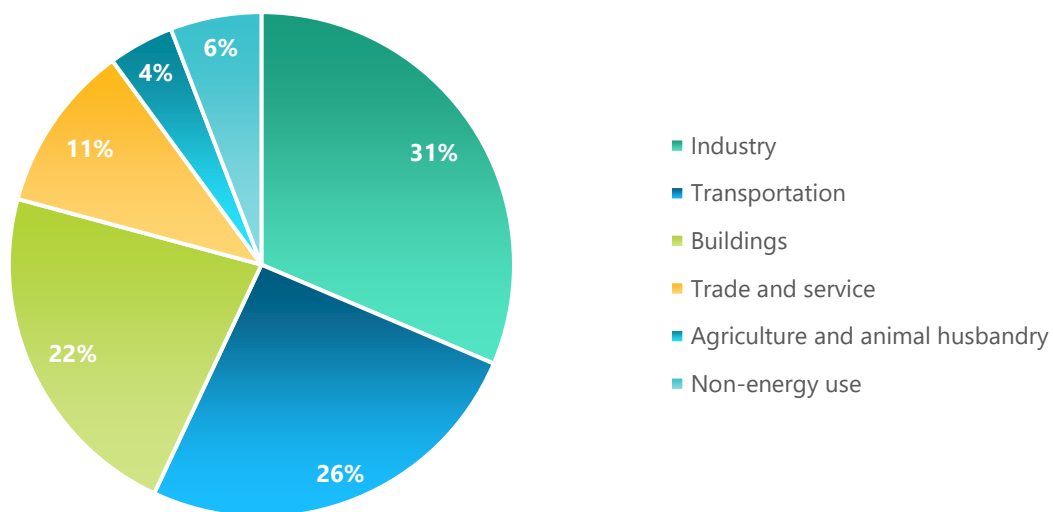


Figure 14. Türkiye's total final energy consumption by sector in 2022 (Ministry of Energy and Natural Resources, 2024b)

Especially in industries with lower levels of electrification, green hydrogen offers significant potential to replace fossil fuel energy sources. This would not only help the industry decarbonize but also enhance the country's energy security. In line with this trend, many firms from diverse industries are actively seeking ways and collaborations to transform their production cycles using green hydrogen. Nevertheless, one common challenge for all the industries discussed in this section is the high levelised cost of hydrogen (LCOH) compared to fossil fuels.

4.3.1 Metal industry

Iron and Steel

Estimations suggest that the green hydrogen demand of iron and steel industry in Türkiye can vary between 0.15 to 0.3 Mt/year by 2050, which will correspond to 16% of the total green hydrogen demand of the country in 2050 (SHURA, 2021b, p. 41).

The first iron and steel factory in Türkiye was constructed in 1937. Since then, Türkiye has established a strong iron and steel industry with 41 crude steel producers in total (3 integrated Blast Furnace – Basic Oxygen Furnace, BF-BOF, 27 electrical arc furnace (EAF) and 11 induction furnace (IF)) (Baş, 2023, p. 117). The total crude steel production in 2023 accounted for 33.7 million tons, and similar to the rest of the world, this production represented a 4% decrease compared to the previous year (ÇİB, n.d.).

While the domestic production has been decreasing since 2021, the demand for crude steel in Türkiye has increased 17% in 2023 compared to 2022 (ÇİB, n.d.), which is normal when the earthquake in early 2023 is considered. Hence, to cover the increasing domestic demand, imports of iron and steel grew 7.7% in 2023 (ITC, 2024).

The EU remained to be the major export destination for Turkish steel (HS Code 72), corresponding to the 33.6% of the total exports (ITC, 2024). This high trade volume is not only due to the geographical proximity of Türkiye to the EU market, but also due to the Agreement between the European Coal and Steel Community and Türkiye dating back to 1996 which allows a tax-free bilateral trade for steel products (Ministry of Foreign Affairs, 2017). However, as of 2026, the CBAM may change this trend, as long as Turkish iron and steel industry does not complete its decarbonization process.

To preserve its trade volume with the EU, the industry in Türkiye, especially the iron and steel producers seek ways to decarbonize their production processes. Hence, a green transformation in the Turkish industry has an utmost priority and needs to be completed way quicker and sooner than the national net-zero target by 2053. In this transformation, the role green hydrogen will play is an undeniable one, making the heavy-industry the major domestic off-taker for the green hydrogen Türkiye will produce. Nevertheless, there are certain factors limiting a faster and wider transition into green hydrogen in the iron and steel industry.

The first factor is the high share of electrical arc furnace (EAF) route with melted scrap metal. 27 out of 41 crude steel producers use and hence are dependent on grid electricity as their primary energy source which accounts for 65% of their total energy demand (Ministry of Industry and Technology, 2020, p. 11). Even though this means greening the energy mix would help decarbonizing those producers to a large extent, it is not an easy task for Türkiye to achieve. As the National Energy Plan (Chapter 2.1.1) points out that Türkiye is investing in new fossil fuel power plants and has not announced a roadmap or plan for phasing out coal. Despite domestic coal reserves and production, Türkiye imports coal and is almost entirely dependent on imports for natural gas and oil. In 2022, 73.6% of the total energy supply was imported (IEA, 2024d). Nevertheless, high share of EAF route within the steel production means there is less need for green hydrogen as primary energy carrier and their carbon footprint is smaller. However, for EAF steel producers with Direct Reduced Iron (DRI), green hydrogen can replace natural gas, which accounts for 30% of the total energy input for this route (Ministry of Industry

and Technology, 2020, p. 11). For EAF with scrap metal, green hydrogen can replace again natural gas in pre-heating processes.

The second factor is the cost. Its impact is twofold: (i) Decarbonization of any steel production facility requires the transformation of the whole system. That is why it is not only complex and a long process but also a costly one. Therefore, access to finance is challenging for firms in Türkiye, where official inflation rate is 68.5% (see Chapter 4.2.1) (ii) Due to increased investments and production costs, the price tag of the end green product also increases, which negatively affects the competitiveness of the firms in the domestic market but also in markets where no CO₂ emission reduction mechanism is in place. Moreover, to our knowledge, there is no financing mechanism specifically designed and offered by the Turkish government to incentivize a green transition in the steel industry. That is why, a common practice for firms with a good R&D department is to get engaged in a Horizon Europe research project, where they mostly collaborate with an international university to study, and hence finance, a system transition specific for their facility.

The third factor is the technical difficulty of installing auxiliary technologies like carbon capture storage (CCS). It is especially relevant for BF-BOF route as it is the traditional steel production method with high energy consumption and carbon footprint. Even though there are only 3 production facilities with this technology in Türkiye, each has a production capacity of over 2 million tons per year (Baş, 2023, p. 117). The option of sequestering carbon in underground raises safety issues as Türkiye experiences often strong earthquakes (Interview 15, 2022). Hence any technology that will be employed in that regard needs to be mature and well-tested for specific conditions in Türkiye.

Aluminium

Türkiye's aluminium sector is a significant component of its industrial economy, characterized by both primary aluminium production and a robust recycling industry. Just like iron and steel industry, the country's aluminium production is also closely tied to its trade relationships, particularly with the EU which is a major export destination for Turkish aluminium products accounting for 63.4% of the total export value (ITC, 2024). The upcoming implementation of the EU's Carbon Border Adjustment Mechanism (CBAM) presents both challenges and opportunities for Türkiye's aluminium industry, particularly in the context of decarbonization and sustainability.

Aluminium can be produced either by converting bauxite to alumina (primary aluminium) or by smelting and refining the scrap aluminium (secondary aluminium). As aluminium's recyclability is very high, when produced via the latter route, its carbon footprint reduces significantly. In fact, it is assumed that 75% of all the aluminium that was ever produced is still in use today (AIT, 2021, p. 10).

For the previous route, green hydrogen can replace natural gas or other fossil fuels in combustion processes to generate the necessary heat. For the latter, just like in the EAF crude steel production, green hydrogen can contribute either as an energy carrier of the renewable electricity or as a reducing agent replacing carbon anodes.

When growing shares of recycled aluminium in Türkiye can be combined with replacement of fossil fuels for heat generation with green hydrogen, it can easily enhance the appeal of Turkish aluminium in international markets, particularly the EU. Nevertheless, it should be noted that

certain challenges that are also valid for other industrial green hydrogen application also applies to the aluminium sector. These are the lack of hydrogen infrastructure, high costs and the difficulty of technological integration into existing recycling facilities. As a sectoral association, the Turkish Aluminium Industrialists Association (TALSAD) works to raise awareness and to close knowledge gaps among the producing firms on the upcoming CBAM regulations by organizing webinars and trainings.

4.3.2 Mineral industry

Cement

In Türkiye, the cement industry is well-developed, benefiting from abundant natural resources and a strategic geographic location. Since required raw materials like limestone, clay or shale are abundant almost everywhere in the country, the cement plants are also distributed across the nation. There are in total 75 cement producers in Türkiye, 19 of which are grinding units and 56 are integrated plants with their own clinker production (TÜRKCİMENTO, 2023). In 2021, Türkiye was the top cement producer in Europe with almost 79 million metric tons, followed by Germany with 35 million metric tons (Statista, 2024). Also for cement, the EU is among the top export destinations for Türkiye, accounting for the 25% of total cement exports in 2023 (ITC, 2024).

Clinker is the main component used in cement production and its share is among the main factors determining whether the carbon footprint of the end product is high or not¹. Reducing the clinker-to-cement ratio by incorporating supplementary cementitious materials (SCMs) can significantly lower the carbon footprint of cement. In Turkish domestic market, CEM I type cement, which consists of 95% clinker, covers 58% of the consumption, while 32% of the consumption is CEM II type with the second highest clinker share (around 65%) (CEMENTIS, 2018, p. 6). According to the Turkish Cement Manufacturers' Association (TÜRKCİMENTO) 1 ton of cement includes on average 86% clinker (TÜRKCİMENTO, n.d.).

Green hydrogen can replace the fossil fuels (mostly coal in Türkiye) used to heat the limestone to high temperatures in clinker production. However, apart from burning fossil fuels, there are also process CO₂ emissions, making cement industry among the most difficult ones to decarbonize. That is why CCS technologies must be integrated as well, to reach complete decarbonization in cement production. The challenges for Türkiye in decarbonizing the cement sector through green hydrogen include the following.

The first challenge is the high clinker content. If the overall cement production is assumed to be 80 million tons, then the clinker consumption for this amount of cement should be around 60.8 million tons (86%). An average cement production plant in Türkiye uses 30,000 tons of coal per year for its clinker production (Interview 14, 2022). If this is going to be replaced by green hydrogen, than only the clinker demand of the cement industry will require an extensive

¹ During clinker production, limestone (calcium carbonate) is heated in kilns to high temperatures, causing it to decompose into lime (calcium oxide) and CO₂. This process, known as calcination, along with the burning of fossil fuels to heat the kilns, contributes substantially to the overall carbon emissions of cement production.

electrolyser capacity (Interview 14, 2022). It is expected that the green hydrogen demand of the whole cement sector will vary between 0.09 to 0.18 Mt/year by 2050 (SHURA, 2021b, p. 42).

The second challenge is the availability of water. If the green hydrogen for the cement industry is going to be produced onsite where the demand is, because the cement plants are scattered around the country, water availability could pose a major challenge as it is not same in every region. In certain areas, aridity is a main problem, even for agriculture or other vital uses. If the green hydrogen production is to be managed in certain central hubs and then distributed to demand sites, then a well-designed transportation infrastructure will be required (Interview 14, 2022).

The third and the final major challenge is the maturity and wide use of complementary technologies like storage and CCS. Even if the green hydrogen is produced on site, storage will be needed as hydrogen input should be adapted to the fluctuations in cement production (Interview 14, 2022). Right forms of storage (e.g. high pressure tanks) should be available based on factors like storage capacity, duration, cost, and infrastructure requirements. Moreover, just like in the BF-BOF route in iron and steel industry, carbon capture is also a must for cement industry to completely abate process emissions. Ensuring safety in dealing with those technologies does not depend on their maturity only, but also the availability of trained and qualified personnel (Interview 14, 2022).

To our knowledge, there is currently no cement production plant that took concrete steps to incorporate green hydrogen into its production process. However, due to coming CBAM regulations, TÜRKÇİMENTO works to raise awareness and to close knowledge gaps through webinars and trainings. They facilitate collaborations with universities in developing tailored models.

Glass

Glass is another heavy Turkish industry with high export shares with the EU. In 2023, 54% of the Turkish glass and glassware exports were sent to the EU (ITC, 2024). Even though its high energy demand makes glass industry one of the major CO₂ emitter, it is not yet included in the initial phase of CBAM regulations. However, in the near future it is expected that the glass industry is also a part of the framework.

In glass industry, hydrogen is used as a feedstock in the production of flat glass. In addition to replacing the already used grey hydrogen, green hydrogen can also replace fossil fuels (mostly natural gas) in glass melting furnaces. However, one major technical challenge is to control for the end quality of the glass product that is produced in hydrogen fuelled furnaces. Moreover, the actors from the Turkish industry believe that long-term effects of hydrogen use in existing melting furnaces that are normally fuelled with natural gas should be researched and observed carefully (Şener Oktik, 2023). Especially lack of applied know-how at the industrial scale might pose additional challenges at the initial stages (Interview 5, 2022). Lastly, similar to iron and steel and cement industries, onsite hydrogen storage is perceived as another important challenge by the glass industry, pointing out the importance of the required infrastructure once again (Interview 5, 2022; Şener Oktik, 2023).

In Türkiye, major glass producers and exporters have already started to investigate ways to switch to green hydrogen as an alternative fuel. For example, Şişecam is among the partners of the HYSouthMarmara hydrogen valley project as one of the off-takers. The company has also become a member of Hydrogen Europe and European Clean Hydrogen Alliance. Together

with greening their 8.3 million m³/a internal hydrogen consumption, they also conduct research to integrate green hydrogen in their existing furnaces (Şener Oktik, 2023).

Ceramic

Similar to other industrial sectors, ceramic is another energy-intensive industry with well-established domestic firms producing wide range of ceramic products targeted at both households and industrial applications. The share of the EU within total exports of ceramic products from Türkiye has reached 47% in 2023 (ITC, 2024).

As one of the pioneers in the Turkish ceramic industry, Kaleseramik is also a partner in the HySouthMarmara hydrogen valley project and will be testing incorporating green hydrogen into their production processes. Similarly, Vitra, another leading ceramic producer, conducts pre-feasibility studies on green hydrogen integration to reduce their burner emissions.

One main challenge for the ceramic industry, similar to glass, is the potential of changing product properties when the burners are fuelled with hydrogen. To analyse exact impacts of hydrogen on the end product, detailed research and pilot studies are necessary (Doil, 2024).

4.3.3 Chemical industry

Estimations suggest that the total green hydrogen demand of the oil refineries and the petrochemical industry will be between 0.03 – 0.06 Mt/year by 2050 (SHURA, 2021b, p. 40).

Oil refineries

Oil refineries process crude oil into refined petroleum products like gasoline, diesel, jet fuel, and produce intermediate products for the petrochemical industry. The biggest oil refinery firm in Türkiye is Tüpraş and it represents 70% of refinery market share. With its 30 million tons of capacity, it is the seventh biggest oil refinery in Europe and the biggest industry firm in Türkiye (Tüpraş, 2024, p. 39).

Tüpraş has announced its Strategic Transformation Plan in November 2021 and pioneered not just the refinery sector, but also the green hydrogen market in Türkiye. As currently the biggest producer and consumer of hydrogen in Türkiye, Tüpraş aims to start its own green hydrogen production in 2025 and become emission free in hydrogen production by 2040 (Tüpraş, 2021). In the period of 2022-2035 the targeted investment volume for green hydrogen production is estimated to be \$690 million (Tüpraş, n.d.). Once their green hydrogen production scales up, they aim to not only meet their own internal demand but also gradually become a supplier of green hydrogen in the market (Tüpraş, 2021).

As part of the transformation plan, Tüpraş wants to become carbon neutral by 2050. Therefore, not only for green hydrogen, but also for the overall carbon neutrality, access to green electricity is essential for Tüpraş. For this, they purchased an energy firm with around 500 MW installed renewable energy capacity and they reduce their dependence on grid by installing captive PV power plants on their refinery sites (Tüpraş, 2024, p. 41).

Moreover, as Tüpraş already produces variety of fuels, they want to use their existing know-how to specialize in biofuels, especially to produce sustainable aviation fuel (SAF). With targeted \$600 million investment capacity, they aim to produce 400 kilo ton biofuels at the initial stages and by 2030 to reach 10% SAF in their total jet fuel sales (Tüpraş, n.d.).

Basic chemical manufacturing

Despite a well-developed chemical industry, Türkiye is a net importer of both ammonia (HS Code 281410) and methanol (HS Code 290511) (ITC, n.d.). For fertilizers, the average production-to-consumption ratio for the period of 2013-2022 is 73%, indicating an import dependency (TBB, 2023, p. 85). Due to nitrogen deficient soil characteristics in Türkiye, urea is the major fertilizer type applied, and the domestic urea production covers only 26% of the consumption (TBB, 2023, p. 85). Import dependency in fertilizer production has already been identified as a challenge by the government and tried to be addressed via different policies in the past (TAGEM, 2018, p. 45).

Green hydrogen can not only support domestic ammonia and methanol production, but also help the country cover its domestic fertilizer demand. To realize this potential, HySouth-Marmara hydrogen valley has given utmost priority to the chemical industry. In that regard, several chemical industrial plants and fertilizer producers of the region are involved in the hydrogen valley and will be testing the production of green ammonia, methanol and then fertilizers at pilot scales (with capacities ranging from 10 MW to 75 MW) by using the green hydrogen produced by other project partners (Interview 12, 2022). This will not only provide secure industrial demand for the green hydrogen producers, but also increase the domestic and green production capacities of strategic chemical feed stocks.

4.3.4 Transport

In addition to the industrial sector, achieving net-zero carbon emissions also requires the decarbonization of the transportation sector. In 2021, transport accounted for 22% of the total CO₂ emissions in Türkiye (IEA, 2024c). Estimates suggest that transportation will account for 50% of the total green hydrogen demand in the country by 2050, corresponding to 0.9 Mt green hydrogen per year if only 10% of the diesel use is replaced (SHURA, 2021b, p. 43). For the decarbonization of heavy transport vehicles like buses, trucks and trains via green hydrogen applications, several initiatives have already been taken both by public and private sectors.

The hydrogen projects in transport sector follow the government's focus on technology development. Compared to developing machinery and technology in other sectors, Türkiye has a great advantage in technology development for vehicles thanks to the decades-long experiences in car manufacturing and the accumulated know-how in that industry. For example, two e-bus firms have already developed fuel cell buses. The first one is Karsan, who produces a fuel cell passenger bus since 2021. The bus (e-ATA Hydrogen) is ready to be ordered and has a range of more than 500 km thanks to its fuel cell engine with 70kW capacity (Karsan, n.d.). Another bus manufacturer, Otokar, has also commercialized its fuel cell bus model (KENT Hidrojen) that runs on hydrogen and has similar metrics to that of Karsan (Otokar, n.d.). It is also known that several other Turkish bus manufacturers currently develop their own fuel cell both city and inner city models, but have not commercialized them yet. The first city in Türkiye who added a hydrogen bus to its fleet was Gaziantep (Parlak, 2024). Since February 2024, Karsan's hydrogen bus runs in the city, which was majorly hit by the earthquake in 2023.

Moreover, the first hydrogen powered truck in Türkiye will be developed by Ford Trucks and CMB.Tech in Ford Trucks' Türkiye factory. The truck will have a dual-fuel combustion engine running on both hydrogen and diesel (Ford Otosan, n.d.). This project is important as it does

not only contribute to the growing hydrogen demand of the transport sector, but it also provides hands-on experience for Turkish automotive industry on hydrogen combustion engines.

Lastly, even though Türkiye does not have a rail system running on hydrogen yet, the diesel locomotive engine developed in the recent years by TÜBİTAK Rail Transportation Technologies Institute (RUTE) and other project partners is planned to be adapted to hydrogen combustion (TÜBİTAK RUTE, n.d.).

5 Outlook and Policy Conclusions

5.1 Potential areas for policy action

Immediate coherent and clear policies

As discussed in Chapter 2.2, Türkiye lacks coherence between announced targets and the policies Erdoğan government implements. As long as there is no roadmap to phase out coal, new coal power plants are installed, fossil fuels are subsidized and the GHG emissions will continue to grow at least until 2038, it will be almost impossible for Türkiye to achieve net-zero by 2053. Another approaching deadline for Türkiye is 2026, by which the CBAM will start its definitive regime. In order for Turkish economy to be well equipped for both of these deadlines, coherent policies with clear measures are needed.

The role green hydrogen will play in reaching those targets has been discussed throughout this report. The Hydrogen Technologies Strategy and Roadmap identifies targets, needs and potentials very accurately for the deployment of hydrogen in reaching climate targets. However, the strategy lacks the answer to the how-question.

Therefore, the strategy should either be revised or supported with additional policies to provide a clear timeline with a break-down of short-term, medium-term, and long-term milestones. It should be clear by whom and how a particular milestone will be achieved. In other words, a detailed action plan should be outlined including:

- (i) how and when the required policy and regulation framework will be updated (e.g. standards and safety regulations, incentives),
- (ii) how the investment and funding mechanism will look like (e.g. specific government budget on grants, subsidies and details on public-private partnerships) and
- (iii) how, when and by whom the required infrastructure for hydrogen deployment will be developed (e.g. location and timeline for production facilities, storage, transportation networks, refuelling stations).

Moreover, as the main focus lies on the technology development, the Hydrogen Technologies Strategy and Roadmap lists the priorities, challenges to reach those priorities and how they can be solved. However, technological and supporting solutions – as they are called in the strategy – also lack clarity. A clear plan of resource allocation, which innovation hubs to be established or supported and their roles in incentivizing innovation either in start-ups or in incumbents could be set.

Despite ambitious targets on hydrogen price and electrolyser capacity, the strategy also lacks a market analysis. In other words, the government's expectations and assumptions on potential national hydrogen demand and production by 2030 and 2053 are unclear. Such assumptions are necessary, to set a plan that channels the market into the desired direction. For example, this plan could include demand stimulation mechanisms like government procurement programs, mandates, and support for hydrogen-powered public transportation, and incentives for industry like tax breaks, subsidies, and low-interest loans. Subsidies can be implement to cover at least a part of the cost difference arising due to the use of green hydrogen instead of fossil

fuels in industry, until the green hydrogen becomes cost competitive in the market. It is especially important to support the decarbonisation of heavy-industries, which requires immediate action.

A plan is implementable as long as there is a suitable workforce who can implement it. Therefore, an education and workforce training plan would give more clarity to the strategy. This might provide details on how the curriculums of vocational schools and universities can be adapted and developed and what kind of training programs are needed to equip the workforce with the necessary skills for hydrogen production, maintenance, and safety.

Lastly, since achieving a hydrogen economy is a long-term task, it might not always be possible to stay on track, even with clear and detailed action plans. Therefore, monitoring and evaluation protocols are essential to ensure progress is being made as planned. These protocols could include progress tracking (e.g. performance indicators) and regular reporting (e.g. performance assessments).

All these details are particularly crucial for internal actors in their financial decision-making processes. Many private firms and their hydrogen enterprises have been mentioned in this report. However, many others could not be mentioned as they have not yet taken any concrete step publicly and hence are waiting for more clarity for their decision-making. If this is delivered, the hydrogen market ramp-up in Türkiye can accelerate even more. Therefore, such a detailed plan would provide clarity and signal both internal and international markets that Türkiye has a clear roadmap and it is very likely that the country reaches its ambitious targets.

Regulation

Regulations provide a structured framework that ensures safety, reliability, and efficiency in the production, storage, distribution, and utilization of hydrogen. Clear and well-defined regulations help to create a stable and predictable environment that encourages investment and innovation, facilitates market development, and ensures public and environmental safety.

In Türkiye, certain legal ambiguities related to hydrogen market and how it is going to function can be eliminated by addressing them with regulations. For example, standardization on definitions of different hydrogen production methods and how hydrogen can be stored, managed, distributed and sold would prepare the legal ground to then issue licences for producers and traders. This would mean that other standards on safety, emissions, sustainability and quality are also set. In Türkiye, the Energy Market Regulatory Authority (EPDK) is, for example, responsible for issuing and managing licences for any type of power plant. The same body can be authorised for hydrogen market as well.

Similarly, certification of end products harmonised with international standards, such as the European ones, is crucial, especially for exporting purposes. The same need also applies to technical equipment that Türkiye will be manufacturing and using for some domestic hydrogen technologies like electrolysers (Interview 30, 2024). This would also facilitate the export of related intermediate technical equipment.

Another regulation clarity could be brought to the way how hydrogen is applied in different case. For example, blending hydrogen into natural gas is estimated to be one of the early and most important applications of green hydrogen in Türkiye (SHURA, 2021b, p. 44). However, the way how natural gas is defined in the respective regulation (Law Nr. 4646) does not allow any

other gas that is artificially produced (including biogas) to be fed into the pipelines. If blending is wished to be applied, then removing such regulative barriers would fasten the process.

Leveraging Existing Expertise

Development of hydrogen technologies is a priority for Türkiye. To accelerate and strengthen this process, Türkiye can draw in foreign companies interested in establishing production facilities and R&D centres. Türkiye's accumulated know-how from its established car manufacturing sector, along with its experience in producing and exporting photovoltaic (PV) panels and wind turbines, positions the country favourably for developing a competitive electrolyser manufacturing sector.

For example, establishing joint ventures between Turkish firms and international leaders in electrolyser technology can accelerate the development process. These partnerships can provide Turkish manufacturers with access to advanced technology and global markets while offering international firms a foothold in Türkiye. Additionally, incentives such as tax breaks, subsidies, and streamlined regulatory processes can be offered to make joint ventures and other types of foreign direct investment (FDI) attractive. Free Zones that are developed in the hinterland of ports in İzmir and other regions offer appealing destination for the manufacturing of hydrogen technologies.

Active involvement in international collaboration

Despite enormous potential and ambitious national targets, Türkiye as a nation has not yet got involved in any regional or international partnerships on hydrogen. Getting involved in such platforms is crucial for a country because it facilitates access to cutting-edge research, technology, and best practices, enhancing the country's hydrogen capabilities. Additionally, such partnerships foster collaboration on infrastructure development, regulatory harmonization, and market stimulation, which are essential for scaling up hydrogen production and usage. The engagement also helps countries attract investment, boost their export potential, and contribute to global efforts to combat climate change.

That is particularly important for countries like Türkiye, whose one of the main distinguishing advantages as a potential exporter is to be in the pipeline range to main demand centres like Germany. However, both during our expert consultations, but also in various professional exchanges with international experts, it was repeatedly stated that a hydrogen pipeline project connecting Türkiye to Germany is seen rather as a political issue. Why and whether that is the case goes beyond the scope of this country study. Nevertheless, strategic regional cooperation with neighbouring countries on joint infrastructure projects like pipelines can help to reduce risks and financial costs.

5.2 Recommendation for international cooperation

A strong domestic green hydrogen market in Türkiye would strengthen its position as an exporter in the global market. Therefore, by supporting the market ramp-up of hydrogen in Türkiye, the actors of international cooperation can assist in enhancing global energy security.

The major potential area for collaboration is joint infrastructure development. This should be a priority for international cooperation as much as it should be for Türkiye (see above). Despite the great demand potential of domestic industry and transportation sector, for Turkish hydrogen producers, this demand is seen rather as an insecure one for now, as the number and scale

of funded or bankable projects are limited. Therefore, any concrete attempt to signal that this infrastructure (e.g. pipelines, international refuelling stations, and production and storage facilities) will be developed collaboratively would boost the number of hydrogen suppliers in Türkiye. For example, even though a joint declaration of intent was signed by the Energy Ministries of Germany and Türkiye (see Chapter 3) in 2022, neither a joint project or nor a collaboration has been announced since. If this declaration would be put in use, it would clear most of the market uncertainties especially for the Turkish private sector and investors.

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