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What role for hydrogen in Turkey's energy future?

1. Introduction

In January 2020, the Ministry of Energy and Natural Resources (MENR) of Turkey organised a consultation meeting with energy sector stakeholders, experts, and academia to define the future of hydrogen in Turkey and to produce a hydrogen strategy by the end of 2021.[1] During 2020, laboratory tests had demonstrated blending 5 per cent, 10 per cent, 15 per cent and 20 per cent into the gas transmission system for households and industry consumption. In January 2021, the Turkish government announced an intention to produce hydrogen from domestically produced energy (lignite, hydro, wind, solar, and geothermal). As a first step, it is intended to blend hydrogen into natural gas distribution grids starting with the Izmir industrial region.[2] Longer term, the country also has enormous potential for hydrogen consumption in the industrial sector. In April 2021, the gas distribution association of Turkey – Gazbir, which is responsible for all testing and research and development (R&D), launched a clean hydrogen centre in Konya, Central Anatolia, which will focus on hydrogen as well as biogas. They successfully tested various levels of hydrogen blending into the natural gas grid.[3] Against that background this paper examines the potential for hydrogen in Turkey and for longer term exports to Europe.

Energy Policy background

Turkey's energy policy is driven more by geopolitical, strategic, and energy security concerns rather than by climate change commitments and emission reduction considerations. Rapid economic growth in the past two decades has led to a steep increase in energy demand and energy imports (especially oil and gas). With the Turkish Lira depreciating against the US dollar over the last few years, the energy import bill, at $46 billion per year, has become a financial burden for the government. This has increased even more during the pandemic with the loss of international tourism, which had been the primary source of foreign currency. With Turkey's October 2021 ratification of the Paris Agreement, and declaration of a target to reach Net Zero by 2053, it is not yet clear how this might change energy policy in future.

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[1] Hidrojen Yaklaşım Belgesi (2020/4B), MENR, https://enerji.enerji.gov.tr//Media/Dizin/BHIM/tr/Enerjide_Arama_Etkinlikleri_ve_Belgeleri/231665-20204bhidrojenyaklasim.pdf
[2] Turkey prepares for hydrogen tests, long-term roadmap as it seeks to use renewable resources, ICIS, https://www.icis.com/explore/resources/news/2020/12/02/10582152/turkey-prepares-for-hydrogen-tests-long-term-roadmap-as-it-seeks-to-use-renewable-resources
[3] Turkey moves closer to hydrogen grid injections, outlines long-term roadmap, ICIS, https://www.icis.com/explore/resources/news/2021/04/12/10627403/turkey-moves-closer-to-hydrogen-grid-injections-outlines-long-term-roadmap

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Turkey's gas import dependence (around 55 per cent in the 2010s) led Russia to attempt to manipulate gas prices to apply political pressure. This was also related to the complex political relations between the countries involving not only energy but Turkey's international orientation. As such, the National Energy and Mining Policy announced by the MENR in April 2017, which focuses on reducing reliance on imported energy resources, is based on three main pillars: 1) improving energy supply security; 2) localisation, including increasing the use of domestic energy resources; and 3) improving predictability in energy markets.

Most of Turkey's current energy goals are targeted for 2023, the 100th anniversary of the Turkish Republic. The MENR's Strategic Plan for 2019-2023 promotes the security of energy supply by increasing indigenous energy production. This includes ambitious targets for renewable energy for 2023. Turkish officials say that the main aim of clean energy deployment in the country is carbon emission reduction.[4] However, Turkey is constructing 7500 MW of new domestic coal power capacity by 2023, aiming to increase the share of domestic sources in new power capacity to 84 per cent.[5] While this is consistent with an attempt to reduce imports and the economic and strategic consequences, it cannot be reconciled with decarbonisation aspirations. In addition, Turkey is developing domestic natural gas production from the Sakarya field in the Black Sea with first gas expected from 2023.

Hydrogen is seen as a potential additional domestic energy supply and Turkey has also started looking into green hydrogen exports to Europe and has carried out preliminary studies of potential markets.

Hydrogen policy still at an early stage in Turkey

The MENR is planning to publish Turkey's hydrogen strategy by the end of 2021 after receiving the findings of R&D conducted by Gazbir-Gazmer.[6] A preliminary roadmap prepared by Gazbir outlines four time periods for hydrogen development in the country:

- 2021–2025: initial pilots, including innovation and demonstration projects, finalise testing of domestic appliances, and start working on a regulatory regime;
- 2025–2030: 10 per cent hydrogen blending (ie. 3–4 per cent by energy content) into parts of the natural gas grid, development of the renewable and low carbon gas market, increasing industry incentives for the production of hydrogen-ready appliances, and development of regulations for transport, storage, distribution and consumption of hydrogen;
- 2030–2040: up to 20 per cent regional hydrogen blending, an increase in hydrogen production, and connecting industrial clusters to hydrogen storage and production facilities by dedicated hydrogen pipelines;
- 2040–2050: widespread use of hydrogen in the industrial sector and residential buildings, distribution lines to be 100 per cent hydrogen compatible, start of hydrogen export, and creation of sufficient hydrogen production and storage capacity.[7]

Turkey is at a very early stage of hydrogen market development. For the successful realisation of these targets, it must identify policy priorities, establish a governance system with enabling policies, and create a system for guarantees of origin for green hydrogen.[8] More generally, there is a range of important technical issues, including standardisation, data quality and transparency, verification and certification to be considered. Indeed, until these prerequisites are put in place, it is difficult to see how low carbon hydrogen will play a significant role in the Turkish energy system, let alone as a supplier of

[4] Turkey Konya blends hydrogen, natural gas for homes, https://www.h2bulletin.com/turkey-konya-blends-hydrogen-natural-gas-for-homes/
[5] MENR, https://enerji.gov.tr/info-bank-energy-diplomacy-detail
[6] Gazbir is the Natural Gas Distribution Association of Turkey. Gazmer was established as the economic enterprise and Technical Centre of GAZBIR in order to consolidate training, certification, audits, R&D and technical studies.
[7] https://cleangascenter.com/
[8] Green Hydrogen: A Guide to Policy Making, IRENA (2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf

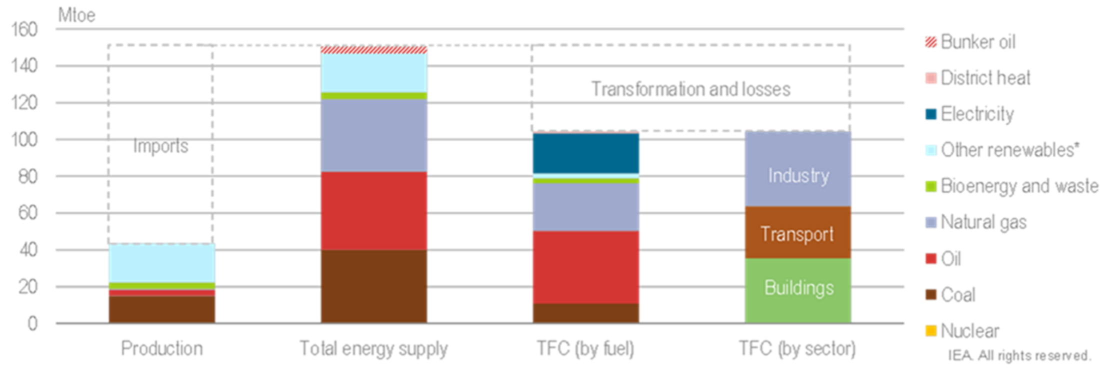
exports to Europe. As such it provides an interesting case study for other countries considering how to incorporate low-carbon hydrogen into the development of their energy economy.

2. Turkey's energy mix and GHG emissions

Overall Energy mix

Turkey's primary energy supply and primary energy consumption increased almost 50 per cent and 40 per cent respectively between 2009 and 2020. Turkey's energy system has been dominated by fossil fuels, accounting for 82 per cent of total primary energy supply. Fossil fuels also make up 71 per cent of total final energy consumption. Around 34 per cent of energy supply is produced domestically, which includes all renewable energy supplies dominated by hydro and half of the coal supplies (Figure 1). Domestic energy production in Turkey had an impressive growth of 61 per cent from 2014 to 2020, driven mainly by renewable sources, thanks to government support mechanisms for mainly wind and solar production. Some 42 per cent of coal and lignite consumption come from domestic supply. Total natural gas demand in Turkey (2020) was 48.2 bcm.[9]

Figure 1: Turkey's energy system by fuel and sector, 2019–2020



Source: International Energy Agency (IEA)

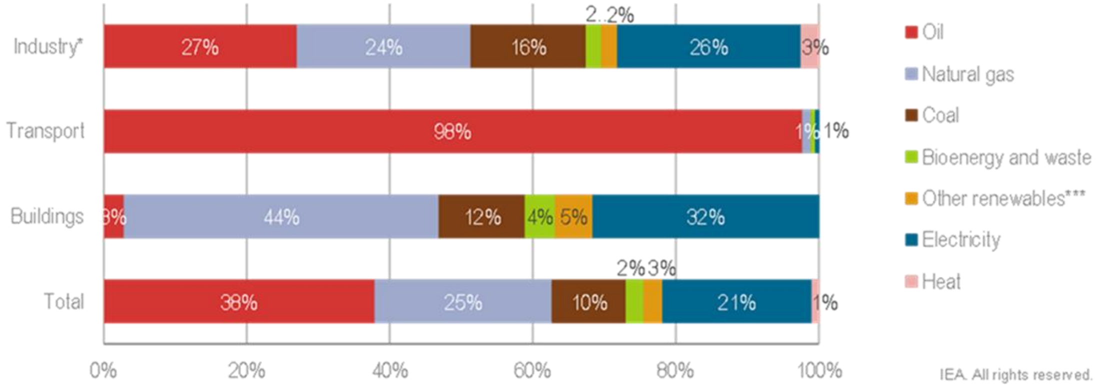
Energy Demand by sector

In 2020 Turkey's total final energy consumption was 150.2 Mtoe (1,745 TWh).[10] The largest energy-consuming sector was industry, accounting for 37 per cent, followed by transport (27 per cent), residential (20 per cent) and services (17 per cent). Oil dominates energy consumption in the transport sector, at 98 per cent of total demand. Natural gas covers almost half of total demand in the residential sector (Figure 2). Industry and services (including agriculture and fisheries) use a mix of oil, gas, coal and electricity.[11]

The country's largest *industry* segments are steel and cement production, which rank in the top 10 worldwide, as well as petrochemical, refinery, production of textiles, machinery, food, beverages, and chemical products.

[9] Energy Market Regulation Authority (EMRA), Annual natural gas Market Report (2020), https://www.epdk.gov.tr/Detay/Icerik/3-0-94/dogal-gazyillik-sektor-raporu
[10] BP Statistical Review of World Energy 2021, 70th edition, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf
[11] Turkey 2021 Energy Policy Review, IEA, https://www.iea.org/events/turkey-2021-energy-policy-review

Figure 2: Total Final consumption by source and sector, 2020



Source: IEA.

Almost one third of Turkey's manufacturing industry total final energy consumption is natural gas. The biggest gas consumers are oil refineries (1.5 bcm/year), chemical and petrochemical industry (1.6 bcm/year), non-metal minerals including cement production (1.7 bcm/year), iron and steel (1.25 bcm/year), food & beverage (0.72 bcm/year) and textile (0.72 bcm/year).[12]

Almost half of the industry sector's total final energy consumption is supplied from imported coal, natural gas and oil products and 26 per cent is supplied by electricity (Figure 2). As local renewable energy sources represent on average only a third of the total electricity supply, the lion's share of energy consumed in the industry sector is supplied from imported fossil fuels.[13] Replacing part of the imported fossil fuels consumed by the industry sector with locally produced green and/or black hydrogen would help reduce its import dependence. Furthermore, more than half of Turkey's manufactured products are exported to Europe and switching to clean energy would potentially increase their competitiveness in the market under a future European border carbon adjustment mechanism.

Oil dominates energy consumption in the *transport* sector, at 98 per cent of total final consumption in 2020. Road transport represents more than 90 per cent of all transport energy demand in Turkey, another 8 per cent of the total energy demand is split between aviation, marine, railways and pipeline transport. Despite the share of EVs (Electric Vehicles) being exceedingly small, with less than 2,000 vehicles (including plug-in and battery EVs) out of 22.7 million road vehicles in total, their share in total car sales is growing.[14] The transport sector is another large potential domestic market for hydrogen consumption, particularly for heavy duty road transport, which would also reduce local air pollution caused by transport emissions.

Another large energy consumer in Turkey is *buildings* and their combined energy use, including those of residential, commercial, and public buildings, accounting for around one-third of the country's total final energy consumption in 2020. Although energy demand in most sectors, especially in the power generation sector has been falling since 2015, the residential sector was one of the few sectors seeing an increase in demand averaging 4.4 per cent per year in recent years. The residential sector's energy demand represents just over half of the entire building sector's total final energy consumption. In 2020 fossil fuels covered almost 60 per cent of total, dominated by natural gas (44 per cent) (Figure 2). In 2020 the country's largest share of total final natural gas consumption came from the residential

[12] Energy Market Regulation Authority of Turkey (EMRA), https://www.epdk.gov.tr
[13] Priority areas for a national hydrogen strategy for Turkey, Shura, https://energy.mit.edu/wp-content/uploads/2021/02/Priority-areas-for-a-national-hydrogen-strategy-for-Turkey.pdf
[14] Priority areas for a national hydrogen strategy for Turkey, Shura, https://energy.mit.edu/wp-content/uploads/2021/02/Priority-areas-for-a-national-hydrogen-strategy-for-Turkey.pdf

buildings, accounting 32.4 per cent. The share of direct use of renewables was around 14 per cent of the total and the share of coal and lignite was 5 per cent.[15]

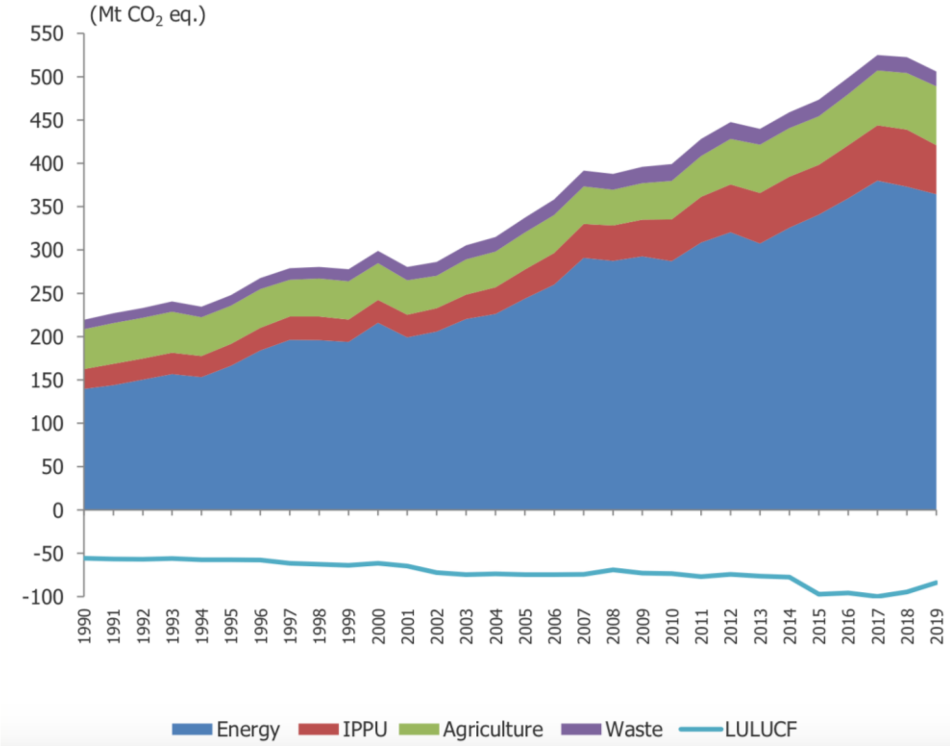
Energy related CO_2 emissions

In 2019 Turkey's total greenhouse gas emissions were 506.1 million tonnes carbon dioxide equivalent (Mt CO_{2eq}) (not including land use, land-use change and forestry (LULUCF)), down 3 per cent compared to 2018, owing to an economic downturn and lower GDP (2 per cent decline from 2018) but an increase of 130.5 per cent compared to 1990. Turkey's total GHG emissions, including the LULUCF sector, were 422.1 Mt CO_{2eq}. in 2019, thus LULUCF served to reduce total emissions.[16] Energy related net emissions have the largest share, accounting for 67 per cent of total emissions in 2019 with the rest coming from industry at 13 per cent, agriculture at 16 per cent and waste at 4 per cent (Figure 3).

Between 2018 and 2019, the only sector having increasing emissions was agriculture (4.1 per cent). The sectors having decreasing trends are industry (14.3 per cent), LULUCF (11.2 per cent), waste (5 per cent) and energy (2.3 per cent).[17]

In the energy sector emissions are mainly from power and heat generation with the lion's share coming from coal combustion. In 2019 coal combustion accounted for 43 per cent of total energy sector emissions. CO_2 emissions in the energy sector are likely to increase as greater reliance is placed on domestic coal and lignite, although this could be offset to some extent by increasing hydro power generation (Figure 4).[18]

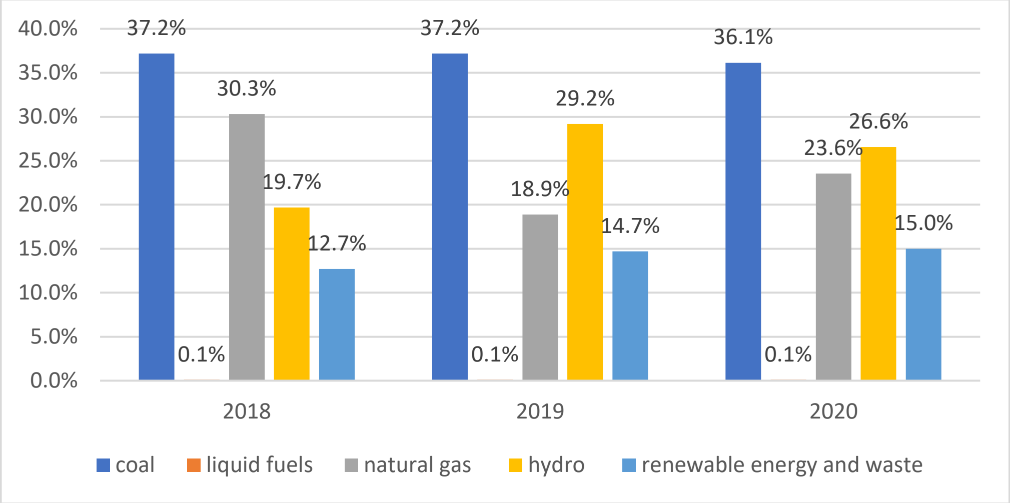
Figure 3: Greenhouse gas emissions and sinks by sector, 1990–2019



Source: United Nations Climate Change (UNCC)

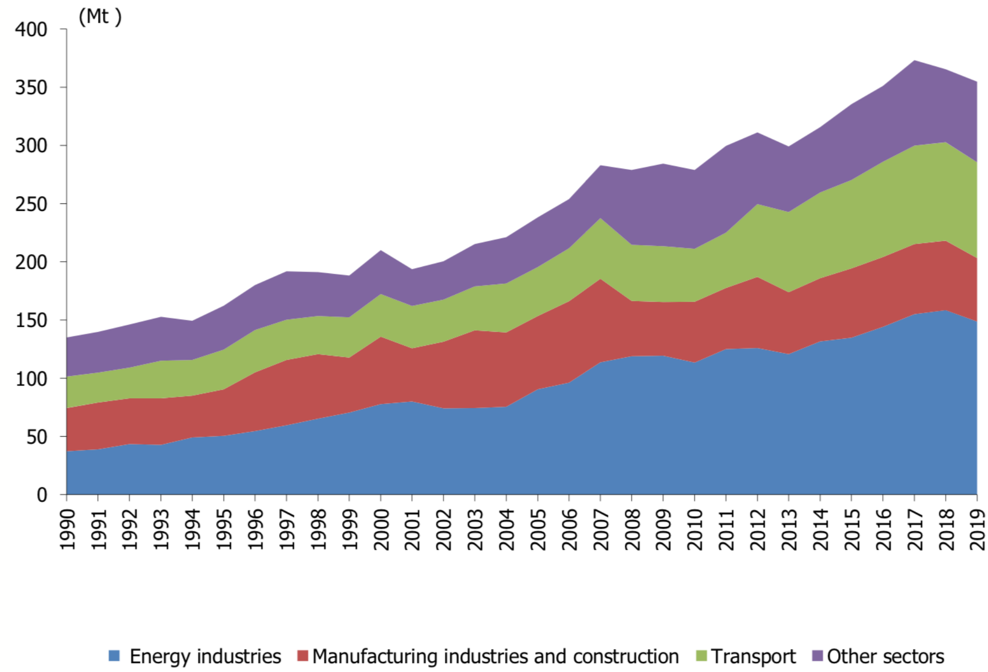
[15] IEA.
[16] United Nations Climate Change, https://unfccc.int/documents?search2=&search3=turkey
[17] Ibid.
[18] Turkey 2021 Energy Policy Review, IEA, https://www.iea.org/events/turkey-2021-energy-policy-review

Figure 4: Electricity generation and shares by energy resources, 2018–2020



Source: UNCC (2018–19), Energy Market Regulatory Authority (EMRA) for 2020.

Figure 5: CO_2 emissions from fuel combustion, 1990–2019



Source: IEA.

Emission reduction commitments, targets and policies

According to Turkey's INDC submitted to the United Nations Framework Convention on Climate Change (UNFCCC), Turkey proposed to reduce GHG emissions by up to 21 per cent from a business-as-usual (BAU) level by 2030 (including LULUCF). Current (2020) GHG emissions are around 600mt

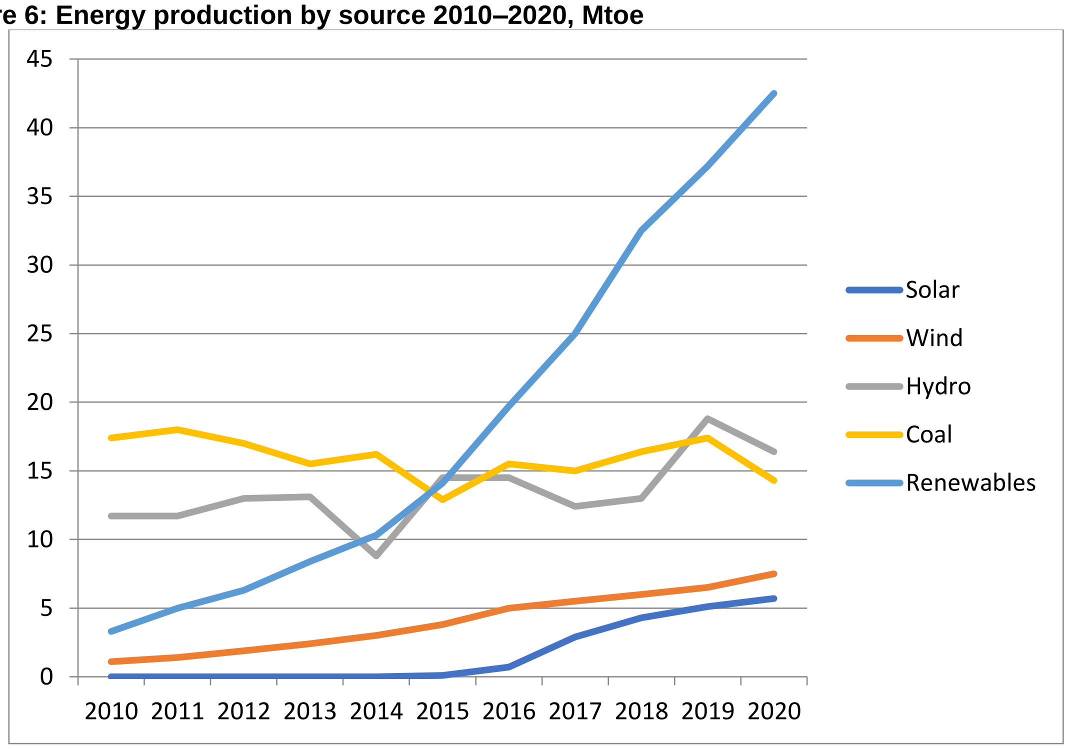
$CO_{2\ eq}$. The BAU forecast for 2030 is 1175 mt$CO_{2\ eq}$ implying a reduction by 246mt to 929mt, but still representing a 50 per cent increase from current GHG emissions.[19]

Turkey has just ratified the Paris Agreement in October 2021, but its NDC is not yet in line with that agreement.[20]. It may yet update its NDC, based on the results of a technical project being implemented by the Ministry of Environment and Urbanization in co-ordination with member institutions of the Climate Change and Air Quality Coordination Board and private sector representatives.[21] Turkey's National Climate Change Strategy, and its implementation plans embodied in the National Climate Change Action Plan (NCCAP) (2011-2023), also have energy efficiency targets that is part of the CO_2 reduction plans. The Turkish government is planning to modify National Energy Efficiency Action Plan for 2017-2023 to achieve more significant emissions reductions.[22]

While Turkey is keen to step up its INDC goal of 21 per cent of GHG reduction from the BAU level by 2030, it experiences financial and technological constraints in combating climate change. Along with national financial resources, Turkey is planning to receive international financial, technological, technical and capacity building support, including finance from the Green Climate Fund.

With twin policy drivers of reducing import dependence and CO_2 emissions, Turkey is increasing the capacity of domestic energy resources, mainly hydro but also solar and wind as well as nuclear power. The country is planning to add 10 GW of solar and 10 GW of wind power by 2027, and to commission the first of four Akkuyu nuclear power reactors in 2023 and a second reactor in 2026. However, with the main objective to increase the share of domestic energy resources it is also adding 7.5GW of coal and lignite generation capacity by 2027.

Figure 6: Energy production by source 2010–2020, Mtoe



Source: BP Statistical Review 2021.

[19] Republic of Turkey Intended National Determined Contribution, UNFCCC, https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Turkey/1/The_INDC_of_TURKEY_v.15.19.30.pdf
[20] https://climateactiontracker.org/countries/turkey/
[21] For more details on Turley's climate change strategy see "Turkey 2021 Energy Policy Review", IEA, pp.42-48
[22] Ibid.

3. Prospects for hydrogen production in Turkey

Economics of blue hydrogen production / potential for CCS

The Oxford Institute for Energy Studies (OIES) has published several research papers on hydrogen and various types of hydrogen production in Europe in general and in major European economies in particular.[23] Most of those papers conclude that as a bridge to "net zero" by 2050, low carbon hydrogen from natural gas with CCS (blue hydrogen) in the short to medium term could potentially hasten the energy transition. On the other hand, waiting for renewable power capacity to become available for the production of green hydrogen would unnecessarily delay decarbonisation and eat into the carbon budget.[24] While this is a logical approach to zero carbon green hydrogen transition in general, it is recognised that each country may have its own path to a hydrogen economy depending on individual circumstances.[25]

Turkey will have its own path towards a hydrogen economy and possibly export in the longer term, and blue hydrogen is likely to be less relevant in this case. The country does not have abundant natural gas resources and all the gas currently consumed is imported via pipelines and LNG from various countries. Turkey's gas discovery in the Sakarya field in 2020 and its gas production after 2023[26] is projected to add from 7 to 15 bcm/year at plateau level, which may start from 2025-26, with total field gas reserves of above 400 bcm. (As noted earlier, current natural gas consumption in Turkey is around 48 bcm/year). Until then, any natural gas for hydrogen production would have to be imported. This would not necessarily be an issue for blue hydrogen production if imported gas prices were low enough. Turkey does not have an import volume constraint given its well-established supply infrastructure - expansion of the entry point send out capacity and ability to import flexible spot LNG from various international suppliers, typically during the peak demand seasons. However, pricing and contracting is an issue for Turkey, specifically in long term contracts (LTCs) with the pipeline gas suppliers.[27] Given that the government target is to reduce imported gas consumption to 20.7 per cent by 2023 (from current 25 per cent) in the power generation sector and replace it with renewables, coal and nuclear to decrease the import deficit bill of $46 billion, there seems little logic to support natural gas use for blue hydrogen production.

In addition, for blue hydrogen, carbon capture, CO_2 transportation and sequestration in a geological structure is necessary. Although Turkey is no longer an oil and gas producing country (the share of domestically produced oil & gas is negligible), it has depleted oil reservoirs, coal veins and deep salt formations in the Batman, Adiyaman and Trakya regions. The total number of existing fields and geological structures in Turkey is 103, 62 (60 per cent) of which are concentrated in Batman just to the south of Ankara, 38 (37 per cent) in Adiyaman province in the southeast and 3 (3 per cent) in the Trakya region in northwest Turkey.[28] As shown in Table 1, the total amount of CO_2 emissions that could potentially be sequestrated in Turkey in geological formations is approximately 108.72 million tonnes

[23] See for example Lambert (2020a) https://www.oxfordenergy.org/publications/hydrogen-and-decarbonisation-of-gas-false-dawn-or-silver-bullet/ , Dickel (2020): https://www.oxfordenergy.org/publications/blue-hydrogen-as-an-enabler-of-green-hydrogen-the-case-of-germany/ , Barnes/Yafimava (2020) https://www.oxfordenergy.org/publications/eu-hydrogen-vision-regulatory-opportunities-and-challenges/ Lambert & Schulte (2021) https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/03/Contrasting-European-hydrogen-pathways-An-analysis-of-differing-approaches-in-key-markets-NG166.pdf, Lambert (2020) "EU Hydrogen Strategy – A case for urgent action towards implementation." OIES https://www.oxfordenergy.org/publications/eu-hydrogen-strategy-a-case-for-urgent-action-towards-implementation/

[24] Dickel (2020): https://www.oxfordenergy.org/publications/blue-hydrogen-as-an-enabler-of-green-hydrogen-the-case-of-germany/

[25] Lambert & Schulte (2021) https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/03/Contrasting-European-hydrogen-pathways-An-analysis-of-differing-approaches-in-key-markets-NG166.pdf

[26] Rzayeva (2020) What are the implications of Turkey's new gas discovery?, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/10/Quarterly-Gas-Review-Issue-11.pdf

[27] For more details on Turkey's LTCs see Rzayeva (2020) The Renewal of Turkey's Long Term Contracts: natural gas market transition or 'business as usual'?, https://www.oxfordenergy.org/publications/the-renewal-of-turkeys-long-term-contracts-natural-gas-market-transition-or-business-as-usual/

[28] Akin, S. (2019) AB Karbon Yakalama ve Depolama Direktifi Düzenleyici Etki Analizi Çalışması Bulguları https://tudoksad.org.tr/upload/files/LCDTR_KYDD_Bulgular_SerhatAkin.pdf

with the largest share in the Batman region. This total storage is small compared to the total CO_2 emissions of around 500 million tonnes per year. Thus, Turkey's CO_2 storage capacity is too limited to store sizeable amounts of CO_2, making it unsuitable for blue hydrogen.

Table 1: CO2 storage potential in Turkey, tonnes

	CO2 storage capacity (ton)
Batman	79.548.418,74
Adiyaman	28.697.172,83
Trakya	473.070,61
Total	**108.718.662,19**

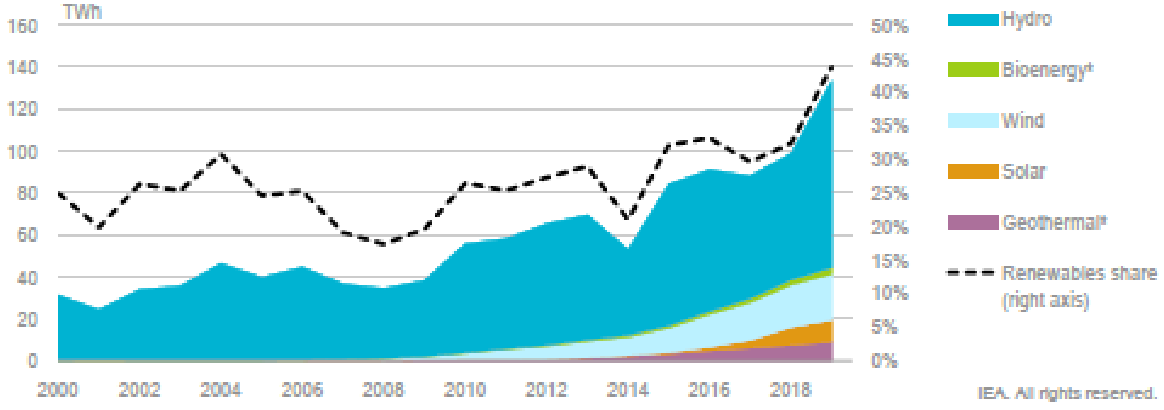
Source: TÜDÖKSAD (Türkiye Döküm Sanayicileri Dernei)

While Turkey only has limited CO_2 storage capacity, it would be theoretically possible to ship CO_2 to countries like Azerbaijan, Russia or Norway for sequestration in depleted oil and gas reservoirs. However, for long-term transportation a dedicated pipeline is needed which would increase the cost of blue hydrogen production. Furthermore, the societal acceptability of CCS has not yet been tested. Combining all these considerations, blue hydrogen is unlikely to play a significant role in Turkey.

Economics of green hydrogen production / required investment in renewable power generation

Turkey had an impressive growth in renewable power generation in the last decade driven mainly by the policy to reduce import dependence. Various governmental support schemes, including a feed-in tariff system under the Renewable Energy Support Mechanism (YEKDEM) since 2011, provide a stable return for ten years. Renewable electricity production, led by growth in hydro, more than doubled in the last decade to 130 TWh[29] (Figure 7). Every year the MENR jointly with YEKA[30] announces auctions for mainly solar and wind production and every auction has resulted in lower costs. In 2021 alone MENR has announced 4,000 MW solar and wind energy production auctions, which will further reduce the production cost.[31]

Figure 7: Renewable energy in electricity generation, 2000–2019



Source: IEA.

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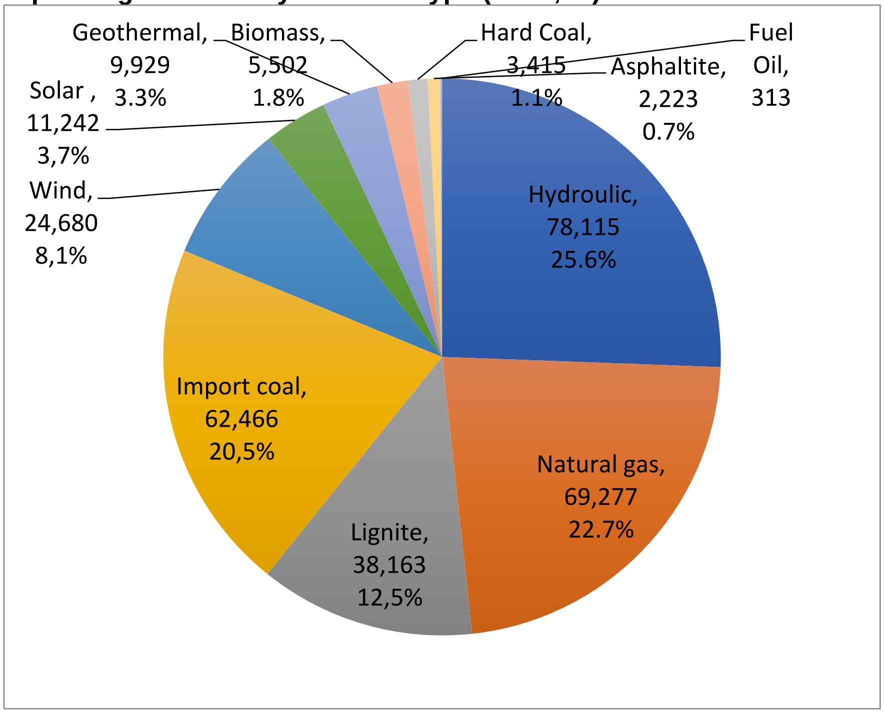
[29] IEA
[30] Renewable Energy Resource Areas (YEKA), introduced by the government in 2016
[31] Bu yıl bir YEKA GES yarışması daha yapılacak, https://yesilekonomi.com/bu-yil-bir-yeka-ges-yarismasi-daha-yapilacak/

Although the share of solar energy was only 3.7 per cent of electricity generation in 2020, the installed capacity of solar increased to around 6,870 MW by February 2021, due to the rapid increase in unlicensed, mainly rooftop solar production between 2017 and 2018.[32] The installed capacity of wind increased almost 4 fold, from 2,261 MW in 2012 to 9,305 MW in 2020 (with 1,225 MW growth in 2020 alone)[33] and is expected to continue to grow in the next decade given the country's significant wind potential, on-going auctions and supportive government policies in the form of feed in tariffs. According to a World Bank report, Turkey has 75 GW offshore wind energy production potential of which 12 GW is fixed (less than 50m depth) and 57 GW floating (up to 1,000 m depth). No offshore wind farms have been built in the Mediterranean yet despite the proximity to demand and favourable wind conditions. However, there are also some factors that limit the country's offshore wind production, namely lack of Exclusive Economic Zones, fragmented jurisdictional waters due to numerous islands along the western coast and only 6 nautical miles of territorial waters on its western coast, leading to competing uses and strong interplay of environmental and social issues.[34] Another major factor is higher production cost compared with onshore wind or solar.

Figure 8: Total power generation by resource type (GWh, %) 2020



Source: EMRA 2020.

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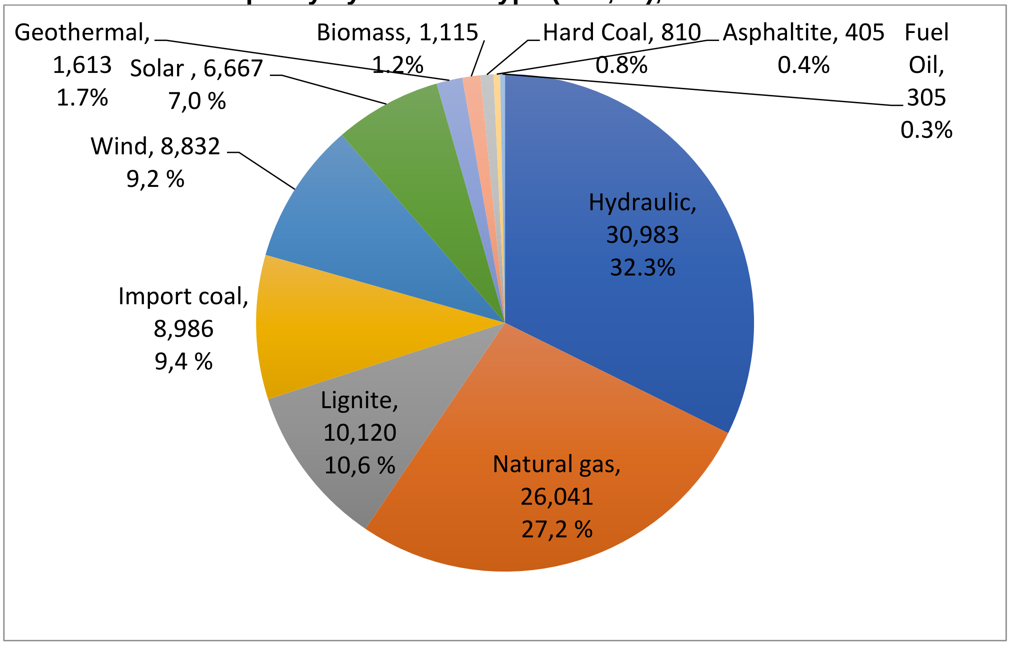
[32] GENSED (Turkish Solar Association), https://www.gensed.org/bilgi-bankasi/grafik-türkiye-güneş-enerjisi-toplam-kurulu-gücü

[33] Turkish Wind Energy Association, https://app.powerbi.com/view?r=eyJrIjoiNmFmYWY0MTYtNjUyNS00NzQ1LWIwMTMtOTI5ZTNkM2FlYWIxIiwidCI6ImU5YzY0NjU4LWFkMWQtNDUwOS1hODk0LTE2NWZhYjU2NjEyMyIsImMiOjl9

[34] Going Global: Expanding Offshore Wind to Emerging Markets (2019), World Bank https://documents1.worldbank.org/curated/en/716891572457609829/pdf/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets.pdf

Figure 9: Total Installed Capacity by resource type (MW, %), 2020



Source: EMRA 2020.

According to the government estimates, Turkey's solar capacity could reach 38 GW and wind capacity 48 GW by 2030[35]. According to some forecasts, 76 per cent of power generation capacity will come from renewables (including hydro) by 2023 but only 61 per cent of power capacity will come from renewable resources by 2027, because the share of hydro energy will decrease after 2025.[36] Another study shows that doubling the total installed wind and solar generation capacity to 40 GW by 2026 is feasible without additional investments in the 400 kV and 154 kV transmission infrastructure (beyond that already planned by TEİAŞ).[37] It remains to be seen how realistic these projections turn out to be.

Wind and solar electricity costs have fallen dramatically over the past decade owing to technology and infrastructure quality improvement, introduction of local content[38], incentives given by supportive government policies, favourable feed-in tariffs and competitive auctions. Since 2010, the cost of solar energy fell from 7 Euro cent/kWh to 1.7 Euro cent/kWh, whereas the cost of onshore wind energy fell from 10 Euro cent/kWh to 5.2 Euro cent/kWh.[39] In the last tender for licensed solar energy capacity announced at the end of May 2021 by YEKDEM, the lowest bid was 1.7 Euro cent/kWh and the highest was 2.2 Euro cent/kWh.[40] The ceiling price for the first wind energy purchase auction, in October 2021, was 45 Turkish kuruş/kWh (0.052 $cent/kWh).

[35] IEA.
[36] Ibid.
[37] Increasing the Share of Renewables in Turkey's Power System: Options for Transmission Expansion and Flexibility (2018), SHURA, https://www.shura.org.tr/wp-content/uploads/2018/12/SHURA_Increasing-the-Share-of-Renewables-in-Turkeys-Power-System_Report.pdf
[38] Turkey imposed a requirement for developers to include high levels of local content in order to qualify for incentives such as premium feed-in tariffs. Future bids will include a minimum local content requirement of 65%. But on the other hand, there is a risk that local content premiums may add to overall system cost.
[39] YEK KANUNU'NDA 7257 SAYILI KANUN'LA YAPILAN DEĞİŞİKLİKLER, pp.12, LBF Partners, http://www.lbfpartners.com/dosyalar/028440.pdf. For the Law see official gazette, YENİLENEBİLİR ENERJİ KAYNAKLARININ ELEKTRİK ENERJİSİ, https://www.resmigazete.gov.tr/eskiler/2011/01/20110108-3.htm
[40] YEKA GES-3'de yedinci gün tamamlandı, https://yesilekonomi.com/yeka-ges-3de-yedinci-gun-tamamlandi/

Electricity sourcing for hydrogen

As is clear from the above, Turkey has significant solar and wind energy production potential and is expected to increase its renewable power generation capacity significantly in future. Currently hydrogen is predominately produced from fossil fuel, mainly natural gas, (without CCUS, CO_2 emitted to atmosphere), and costs are 3-4 times cheaper than green hydrogen.[41] While Turkey has relatively low cost renewable power, government support will still be required to stimulate green hydrogen production. Furthermore, the first priority for renewable power generation will be to decarbonise the power grid, so significant green hydrogen production can only realistically be considered once renewable power exceeds end use electricity demand.

The economic feasibility will also depend on the electricity sourcing option - electricity supply from dedicated plants (off-grid), offshore or onshore wind and solar, and electricity supply from the grid.[42].Low carbon dedicated power plants have the benefit of low cost electricity and the certainty that whenever electricity is available it will be used for hydrogen production. On the other hand, running hours and electrolyser utilisation will be limited to the availability of the dedicated power plant, typically 2,000 full load hours per year for solar and 3,000-4,000 hours for offshore wind. Alternatively, using grid-based electricity could enable higher running hours, but will be associated with the average carbon intensity of the power grid (currently relatively high at around 400 g CO_2/kWh).[43]

Electricity supply from dedicated plants: Renewable electricity (RES)-based hydrogen cost in Turkey largely depends on capacity factor. In general, the RES capacity factor, and hence electrolysis full load hours, is low, at around 21 per cent, resulting in high CAPEX impact on the Levelised Cost of Hydrogen (LCOH).[44] Onshore wind energy is positioned better with a higher average capacity factor around 30 per cent. The highest capacity factor region for wind (45 per cent) is the western part of Turkey, the Trakya region, the Aegean, eastern Mediterranean and Marmara, whereas the lowest (10-15 per cent) is the central, eastern and southeast regions. CAPEX and OPEX of RES and electrolysers are used to calculate the LCOH. Based on the techno-economic assumption for electrolysers made by The Institute of Energy Economics at the University of Cologne (EWI) as shown in Table 3,[45] LCOH is computed for the year 2030 at between $2.8 and $3.3/kg for green hydrogen using PV electricity and $5 to $6/kg using wind electricity, clearly demonstrating the benefit of PV generation in Turkey.

Table 3: Cost of electrolyser

		2030
Low temperature	CAPEX ($/kW)	625
	OPEX (per cent CAPEX/year)	2
	Efficiency (per cent)	68
	Lifetime	25
High temperature	CAPEX ($/kW)	1800
	OPEX (per cent CAPEX/year)	2
	Efficiency (per cent)	80.5
	Lifetime	25

Source: EWI.

[41] YEKA RES-3 yarışma ilanı yayınlandı, https://yesilekonomi.com/yeka-res-3-yarisma-ilani-yayinlandi/
[42] Contrasting European hydrogen pathways, OIES
[43] IEA Turkey Energy Policy Review 2021, p38
[44] Ibid.
[45] Brändle et al, Estimating Long-Term Global Supply Costs for Low-Carbon Hydrogen (2020), EWI, https://www.ewi.uni-koeln.de/cms/wp-content/uploads/2021/05/EWI_WP_20-04_Estimating_long-term_global_supply_costs_for_low-carbon_Schoenfisch_Braendle_Schulte.pdf

Hydropower is the largest source of renewable electricity in Turkey and accounted for 26.6 per cent of total electricity generation in 2020. The availability of hydropower depends on hydrological conditions such as the annual pattern of snow melting and high precipitation in spring and can vary significantly year on year. Run of river hydro generation peaks between mid-April and mid- June; during May levels are consistently above 80 per cent of maximum capacity, while they drop to 20-40 per cent during the period of September to January.[46] It is expected that hydropower generation will grow rapidly over the next 3-5 years but the rate of growth will decrease after 2023 in the absence of planned development beyond projects currently under construction. According to government estimates, Turkey's hydroelectric potential is 433 TWh, while the technically usable potential is 216 TWh and the economic potential 160 TWh/year. Based on projects already under construction, it is expected that hydropower capacity will reach 32 GW by 2023, generating around 150 TWh/year, indicating that a sizeable share of Turkey's economic potential will be realised by then.[47] This means that after 2023 the share of hydropower is likely to fall, affecting the overall share of renewable energy in the electricity generation sector. For this reason, hydropower is unlikely to make a significant contribution to production of green hydrogen in Turkey.

Economics of black/brown hydrogen production from coal / lignite

In 2020 the share of coal (including lignite) in total primary energy supply in Turkey was 28 per cent, with 33 per cent share in electricity generation. The share of coal in electricity generation increased by 10 per cent since 2010, while its share in total final consumption decreased by 9 per cent. Turkey produces 70 per cent of total coal consumption in terms of mass, but around 42 per cent in energy terms, as domestic production is mainly lignite with low calorific value compared to imported steam coal. Furthermore, domestic production has fluctuated in the last decade, while imports have steadily increased. After decreasing in 2009-15, coal production grew by 38 per cent in the four years from 2015 to 2019, reaching 115 million tonnes (Mt) or 14.3 Mtoe in 2020.[48] In 2020, lignite accounted for 96 per cent of total domestic coal production (in mass terms). Turkey's lignite resources are low in energy content; 79 per cent of lignite has a calorific value below 2,500 kcal/kg.[49]

The government policy is to increase coal production and its share in power generation sector in line with the strategy to reduce dependence on imported natural gas for mainly economic and energy security purposes. To this end, the government targets to add 7.5GW of new lignite power generation capacity by 2027, although this may change depending on the result of ongoing studies on coal reserves by government. This is in addition to 11.3 GW of existing installed electricity capacity fuelled by domestic coal in 2020. Installed capacity for imported coal was 9.0 GW. Turkey has proven reserves of 19.14 billion tonnes of lignite and 1.6 billion tonnes of hard coal, and government is planning to find new coal fields, which could double reserves.[50]

Any possibility of hydrogen production from coal (known as black hydrogen) looks very unlikely in Turkey for three main reasons:

- Firstly, domestic mining and burning of low-quality lignite and coal considerably impacts local air quality with a number of adverse effects on human health. Turkish Coal Enterprises and Turkish Hard Coal Enterprises, two state monopolistic entities that explore for and produce lignite and hard coal, have been actively exploring the potential of clean coal technologies through various R&D projects financed by the government to extract the energy content of lignite without mining it.[51] However, thus far no results in these efforts have been achieved.

[46] Increasing the Share of Renewables in Turkey's Power System: Options for Transmission Expansion and Flexibility (2018), SHURA.
[47] IEA
[48] BP Statistical Review 2021
[49] IEA
[50] Ibid.
[51] Ibid.

- Secondly, electricity from coal-fired generation is more expensive than other locally produced energy. The government subsidises coal-fired power generation, buying electricity from generators for a higher price (6.04 $cent/kWh) than prevailing market prices of around 4-5 cents. [52] It subsidises the difference in the price at which it sells the electricity to the wholesale market.
- Finally, production of hydrogen from coal would run counter to any longer term decarbonisation objectives.

Economics of yellow hydrogen production (from nuclear power)

Turkey has been planning to build its first nuclear power plant (NPP) since the mid-1960s. The first decisive step was taken in 2010 by the signing of an intergovernmental agreement with Russia to build a first NPP in Akkuyu in the southern part of the country and in 2013 with Japan to build an NPP at Sinop in the north. The construction of the first VVER-1200 type of reactor at Akkuyu started in April 2018 after the project received all the licences and permissions from the Turkish government. Russian Rosatom owns 100 per cent currently and, according to the agreement signed with Turkey, its share will always be at least 51 per cent. After 15 years, when the plant is expected to be paid off, the project company will pay 20 per cent of the profits to the Turkish government.[53] The Akkuyu Project Company (APC), is implementing the project on a build-own-operate (BOO) model and is responsible for the construction and operation of four units of the Russian VVER design by 2026, each with a capacity of 1200 MW (Table 4).

Table 4: Under construction, planned and proposed nuclear power reactors

	Type	MWe	Start construction	Palnned startup
Akkuyu1	VVER-1200/V-509	1200	April 2018	2023
Akkuyu2	VVER-1200/V-509	1200	April 2020	2024
Akkuyu3	VVER-1200/V-509	1200	March 2021	2025
Akkuyu4	VVER-1200/V-509	1200	2022	2026
Sinop1	Atmea 1	1150	uncertain	
Sinop2	Atmea 1	1150	uncertain	
Sinop3	Atmea 1	1150	uncertain	
Sinop4	Atmea 1	1150	uncertain	
Igneada1-4	AP1000x2,	2x1250		
	CAP1400x2	2x1400		

Source: World Nuclear Association.

Electricity Generation Joint Stock Company (EÜAŞ) agreed to buy a proportion of the generated electricity at a fixed price of 12.35 $cent/kWh for 15 years. The proportion will be 70 per cent of the output of the first two units and 30 per cent of that from units 3 & 4 over 15 years from the start of commercial operation. The remaining power will be sold by APC on the open market for market price.[54]

With the Sinop nuclear project the situation is less certain. Initially it was agreed in an Intergovernmental Agreement (IGA) that the consortium led by Mitsubishi, Itochu and Engie would own up to 49 per cent, with the majority share belonging to the government of Turkey with EÜAŞ serving as the Turkish

[52] Ibid.
[53] World Nuclear Association, https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/turkey.aspx
[54] Ibid

shareholder. The Turkish Electricity Trading and Contracting Company (TETAŞ) was to buy 100 per cent of the output in accordance with the IGA with 20 years guaranteed purchase of 4,600 MWe of generated electricity. However, in December 2018 the project was cancelled by the Turkish government because feasibility studies presented by Mitsubishi fell short of the ministry's expectations regarding the construction budget and the schedule for its completion. In January 2020 the energy minister said the government was reviewing its choice of partner.[55]

Nuclear power could be attractive as a feedstock for hydrogen as it can be considered low carbon and operates at a higher capacity factor than renewable power. In addition, the short run marginal cost (SRMC) of nuclear power will be the lowest among other thermal power plants, although higher than renewable power generation. However, given the high CAPEX, the feed-in tariff of nuclear electricity is the highest, which makes it expensive for the government as a buyer of 50 per cent of this electricity to consume as feedstock and needs to be subsidised. This would make yellow hydrogen production in Turkey uneconomic, unless nuclear power were available in excess of power market requirements.

4. Potential use of hydrogen in Turkey in key sectors

Turkey's total final energy consumption in the industry sector at 645 TWh is 38 per cent of total energy demand. The industry sector consumes half of all Turkey's total net electricity output and the share of electricity in the sector's total final energy consumption is over one quarter. Nearly half of manufacturing industry's total final energy consumption is supplied from imported hard coal, natural gas and oil products.[56]

Hydrogen is not a new energy carrier for Turkey and has been widely used in oil refining and chemical and petrochemical production. Production of hydrogen in these industry segments is mainly from natural gas and a minor share comes from oil and coal. This experience of production, transportation and industrial use of hydrogen may help in the introduction of cleaner hydrogen[57] in Turkey.

Refining sector

The top industrial user of hydrogen in Turkey is oil refining which consumes by-product hydrogen typically manufactured on-site and emits some 7,000 kt/year CO_2. The share of GHG emissions as $CO_{2\,eq}$. from petroleum refining in the energy industries sector was 4.7 per cent in total 2019 emissions.[58] Total current crude oil processing capacity of Turkey's refineries amounts to 43.6 Mtpa (Tüpraş across four cities 30 Mtpa; SOCAR 10 Mtpa and Petkim 3.6 Mtpa). While the characteristics and complexity of refineries could vary substantially, we estimate approximate hydrogen production/demand in refineries based on crude oil processing capacity. Given the total refinery distillation capacity, a very rough calculation suggests approximately 334,000 t/year of hydrogen production requiring around 2.5 GW of electrolyser capacity to meet the hydrogen demand of all refineries.

Under current trends overall hydrogen demand in the refinery sector will be growing by 2030 given the demand growth in refined products.[59] Turkey's five operational refineries meet around 72 per cent of the country's oil products demand. The use of low carbon hydrogen in the refining sector will depend on the economics and government support. As already explained, there is a storage capacity limit that makes CCUS application technically constrained, so low carbon hydrogen is likely to be produced by electrolysis. Electrolytic hydrogen from renewable energy will tighten the refinery margin in what is

[55] Ibid.
[56] Shura https://shura.org.tr/en/priority-areas-for-a-national-hydrogen-strategy-for-turkey/
[57] Lambert, M. (2020) Hydrogen and decarbonisation of gas: false dawn or silver bullet? https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/03/Insight-66-Hydrogen-and-Decarbonisation-of-Gas.pdf
[58] National Inventory Report for submission under the United Nations Framework Convention on Climate Change, UNFCCC
[59] Turkey's Robust Refined Fuel Demand To Give Ground In The Wake Of Rising Covid-19 Cases, https://www.fitchsolutions.com/oil-gas/turkeys-robust-refined-fuel-demand-give-ground-wake-rising-covid-19-cases-17-12-2020?fSWebArticleValidation=true&mkt_tok=NzMyLUNLSC03NjcAAAF_8F5vDXLJB20LuoOraqoxRMgoZJpfYunLOPPaeJQQKjUH18BIn4rVb605Vay_MJ2TYBdpX40Lyb5MB7XaYWXoJmxXx6jXGLp4BA7dN35E2MvMTBbFhg

already a highly competitive refinery industry. Given that there is no carbon price in Turkey and no emission restrictions, there is currently no incentive for the industry to decarbonise hydrogen. In the longer-term to make this happen, government support is important with the introduction of relevant regulation, for example, introduction of CO_2 prices or emission restrictions.

Chemical and Petrochemicals production

There is a single petrochemical producer in Turkey - Petkim. The plant has a single steam cracker with a 520 kt/year production capacity of ethylene using 100 per cent of naphtha as feedstock material. There is no methanol or ammonia production in Turkey.

Total final energy consumption of the petrochemical sector is 1.7 Mtoe/year with 4.3 $MtCO_2$/year emission (Table 5).

Table 5: Current and future hydrogen demand and investments in selected industry sectors in Turkey

	Future hydrogen demand for 5-15 per cent substitution (Mtoe/year)	Installed electrolyzer capacity needed (GW)	Installed renewable power capacity needed (GW)	Total investment needed (USD bn)
Chemical, Petrochemical	500	1.3	4.0	5.0
Iron and Steel	405	1.1	3.2	4.0
Cement	1200	3.2	9.5	11.9

Source Shura (Enerji Dönüşümü Merkezi).[55]

Hard to decarbonise sectors – iron, steel and cement production

In total Turkey has 32 iron and steel plants. It is the eighth biggest iron and steel exporter in the world, and the biggest trading partner is the EU. The majority of steel plants are clustered in the coastal areas of Iskenderun-Osmaniye, Izmir-Aliaga, Marmara and the Western Black Sea where the majority of solar and wind power plants are located.

Most liquid steel in Turkey is produced in integrated iron and steel plants with Blast Furnaces and Basic Oxygen Furnaces (BOF) producing from ore using coal, and Electric Arc Furnace (EAF) plants producing from scrap. The BOF method is currently used in Turkey's three largest iron and steel plants.

Decarbonisation of steel is most likely to require changing the process to hydrogen-based DRI.[60] That will require significant new investment and a higher cost input (renewable hydrogen rather than coal), so the resulting steel will be more expensive, and so may struggle to compete in global markets. However, the proposed European Carbon Border Adjustment Mechanism may provide an incentive for Turkey to invest in DRI rather than pay the EU carbon price, but that will depend on details of the mechanism, which are still to be defined.

Cement sub-sector

This is one of the largest energy consumers despite using mainly new and efficient rotary kiln technologies. Most of the kilns in Turkey use coal, petroleum coke, and lignite as the primary energy source. Total energy consumption of this industry is 6.4 Mtoe and CO_2 emissions are 21.3 $MtCO_2$/year which includes cement process emission.[61] Low carbon hydrogen could only reduce emissions from

[60] For more details of this process see Oxford Energy Forum No 127 (May 2021), p22 https://www.oxfordenergy.org/publications/oxford-energy-forum-the-role-of-hydrogen-in-the-energy-transition-issue-127/
[61] SHURA

energy use, but the process emissions make the sector complex to decarbonise. A total of 76 cement plants in the country are spread across the entire country so any hydrogen use would require decentralised production or delivery by pipeline.

Power Generation Sector

As described in section 3, Turkey has significantly increased the share of renewables in power generation and it will continue to grow in the future. Green hydrogen could be a good solution to balancing intermittent renewables and for long term electricity storage. With further growth of solar and wind energy production in Turkey in the mid- and long-term, the need for storage will increase. Production of a very large volume of hydrogen from renewable power in combination with hydrogen storage can help provide long-term seasonal flexibility to the system and minimise curtailment when energy production is high and demand is low.[62] For such long term seasonal storage hydrogen is best stored underground, ideally in salt caverns.[63] Turkey has a large salt cavern natural gas storage facility, currently being increased to 5.4 bcm capacity.[64] Consideration could be given to phased conversion of this facility to hydrogen storage. However, it must be stressed that the first priority for renewable power will be to reduce fossil fuel consumption in the power sector, so green hydrogen will only be relevant for balancing the power grid once intermittent renewables have reached well over 50 per cent of power generation capacity.

5. Possible conversion of gas infrastructure to carry hydrogen, including blending

Turkey has the 6th longest natural gas distribution network in Europe with 150,000 km of pipelines. Botas is the monopoly owner of the gas transmission system and the monopoly supplier to wholesalers which then supply gas to the gas distribution companies. 82 per cent of the population has access to natural gas and 55 million people have a direct access to the natural gas distribution network. Turkey has an ambitious plan to blend 20 per cent of hydrogen into parts of its gas distribution network by 2030.[65] Given the lower energy density of hydrogen compared with methane, a 20 per cent blend by volume equates to approximately only 7 per cent by energy content. As hydrogen will be a domestically produced energy carrier, Turkey would also slightly reduce its natural gas import volumes, thus improving its trade deficit.

The current Botas gas quality specification does not contemplate hydrogen blending.[66] However as the country's hydrogen strategy is due to be published by the end of 2021 it is likely that pipeline regulation of hydrogen blending will also be published with the strategy. Having a monopoly supplier with the whole system centrally managed will potentially ease the process of introducing hydrogen into the network.

As a general guideline from IRENA, in a gas pipeline up to 30 per cent of hydrogen blend is assessed as harmless to safety and no major technical modifications are needed. For higher blends further specific studies are required.[67] The level of acceptable hydrogen blend differs in various system components. For example, in compressor stations only 2 per cent blending is assessed as harmless without further checks and modifications. The only type of pipelines that can be 100 per cent converted to hydrogen transportation infrastructure safely without further study are plastic pipelines.[68] As Botas

[62] HYDROGEN: A RENEWABLE ENERGY PERSPECTIVE (2019) https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf
[63] Ibid.
[64] https://www.aa.com.tr/en/energy/natural-gas/turkeys-salt-lake-to-increase-gas-storage-by-2023/23932
[65] GAZBİR Doğal Gaz Sektörü Hidrojene Geçişte Yol Haritası Önerileri, https://www.cleangascenter.com/assets/files/Gazbir-GazmerHidrojenYolHaritasiOnerisiRaporu.pdf
[66] Botaş transmission network operation principles 01/12/2007, www.botas.gov.tr
[67] IRENA 2018, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf
[68] Ibid.

pipelines are all steel it is likely that maximum 30 per cent hydrogen blend can be safely transported without major technical modifications but detailed analysis of the overall system will be required on a case by case basis.

In addition, the introduction of hydrogen blends can have an impact on use of gas in many end consumer applications. Some demonstrations of up to 20 per cent blends for distribution to households are being carried out in some countries[69], but for many industrial users (e.g. glass, ceramics, gas turbines) equipment is much more sensitive to hydrogen blend level and will need to be assessed in each case.

Gazbir-Gazmer's Clean Energy Center in Konya, which is conducting research and development of hydrogen production, transportation and consumption in Turkey, has successfully completed a test of 5,10, 15 and 20 per cent of hydrogen blending in the gas distribution network and its consumption in residential buildings. However further long-term tests, research and analysis are needed for defining the safe level of hydrogen blending for the overall system.[70]

Hydrogen blending would not allow delivery of pure hydrogen to industry and the residential sector, as separating the hydrogen from the natural gas stream on exit is not currently possible on a large scale and would in any case be costly.[71] Blending is also of limited value for decarbonisation, as blending of 15 per cent by volume results in just a 5 per cent carbon-free energy content – a very modest outcome for hydrogen demand and market development, although it could provide a useful outlet for initial small hydrogen volumes.[72]

6. Longer term prospects for potential exports

Turkey has an ambitious plan to start exporting low carbon hydrogen in the longer-term mainly to the European market, competing with the countries of the MENA region. Turkey has some competitive advantage from geographic proximity to the markets, low-cost renewable energy production and supportive government policy. In addition, natural gas export pipelines such as the Transadriatic Pipeline (TAP) and interconnectors between Turkey, Greece and Bulgaria could potentially transport blended hydrogen initially and 100 per cent hydrogen in the longer term. However, it is unlikely that export of low-carbon hydrogen from Turkey will make sense until renewable power generation capacity has achieved a high share of the Turkish power grid.

Potential markets

The closest potential hydrogen markets for Turkey could be in Eastern, South-Eastern and Central Europe which could be reached with existing pipelines and interconnectors at relatively low cost.

Over the last 2-3 years there have been intense discussions in Europe on hydrogen market development, including by the main decision-making bodies such as the European Commission, oil majors, TSOs and energy regulators. The EU intends to provide funding for hydrogen projects through mechanisms such as International Projects for Common European Interest (IPCEI). Initially small fragmented markets are likely to develop with bilateral trades between suppliers and off-takers which could then develop into hydrogen clusters. Demand for low carbon hydrogen will need to be created through carbon pricing, quotas, incentives and other mechanisms.[73] In its European Hydrogen Strategy, the EU targets 80 GW of electrolyser capacity of which 40 GW will be for imports from neighbouring

[69] See for example: https://hydeploy.co.uk/

[70] GAZBİR Doğal Gaz Sektörü Hidrojene Geçişte Yol Haritası Önerileri, https://www.cleangascenter.com/assets/files/Gazbir-GazmerHidrojenYolHaritasiOnerisiRaporu.pdf

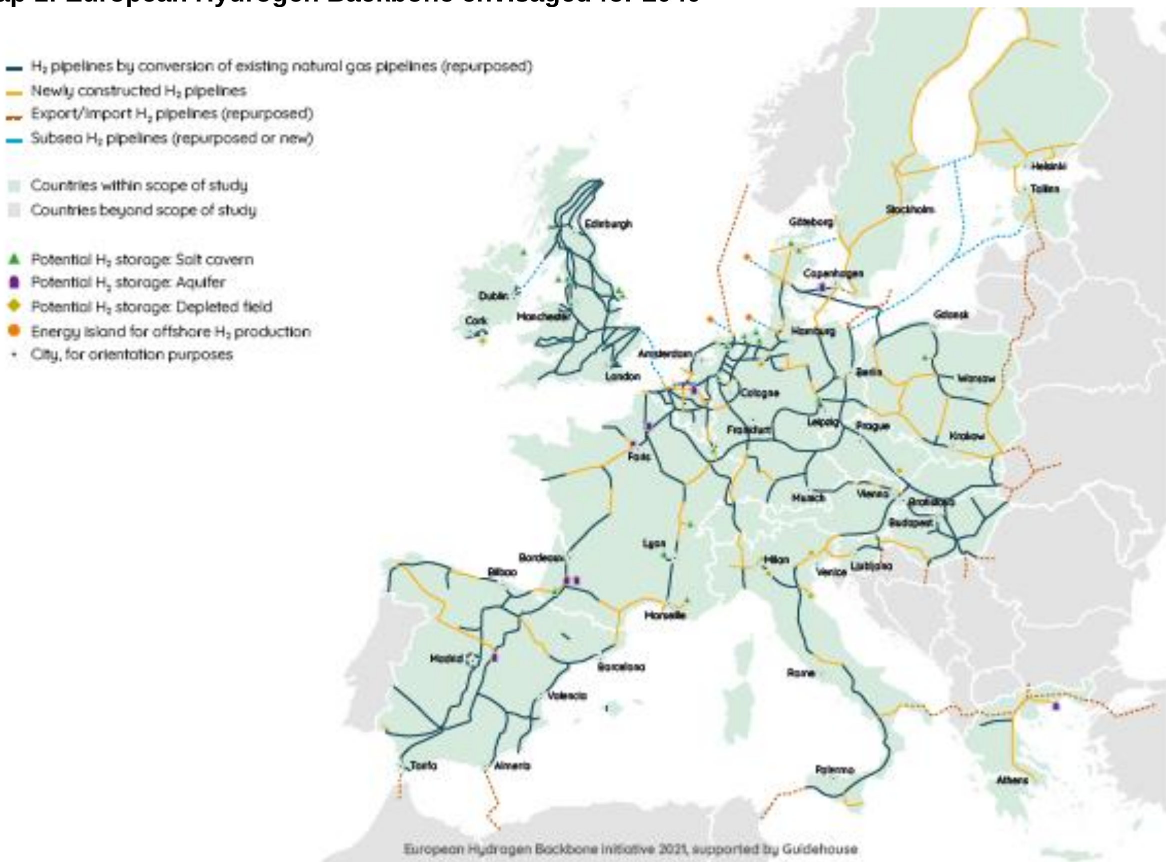
[71] Dickel: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/06/Blue-hydrogen-as-an-enabler-of-green-hydrogen-the-case-of-Germany-NG-159.pdf

[72] Ibid.

[73] Hydrogen Act: Towards the Creation of European Hydrogen Economy (2021), https://www.hydrogeneurope.eu/wp-content/uploads/2021/04/2021.04_HE_Hydrogen-Act_Final.pdf

regions, with Ukraine and North Africa being mentioned specifically. Given its geographic proximity and low cost renewable power, Turkey may also seek to be a potential supplier of hydrogen imports to Europe,[74] but, as noted above, this will only make sense with further expansion of renewable power generation.

Map 1: European Hydrogen Backbone envisaged for 2040



Source: European Hydrogen Backbone (EHB).

Potential Conversion of TAP for hydrogen export

The European Hydrogen Backbone (EHB) (Map 1), a consortium comprising 23 TSOs from 21 countries has an ambitious hydrogen network plan to reach a total length of 39,700 km by 2040 of which 69 per cent is repurposed pipelines and 31 per cent is new build.[75] The Transadriatic pipeline (TAP) is also included in the proposed EHB for 2040 as a repurposed export/import pipeline for hydrogen. Indeed, the TAP developers have started a study on the technical feasibility of blending up to 20 per cent of hydrogen.[76] Italian SNAM is one of the infrastructure operators in Europe conducting several studies into repurposing its natural gas pipelines. TAP could become an important hydrogen import pipeline for Europe, importing from Turkey but also potentially from Azerbaijan and the eastern Mediterranean via the Trans Anatolian pipeline.

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[74] Germany looking at green hydrogen imports from Turkey, https://www.dailysabah.com/business/energy/germany-looking-at-green-hydrogen-imports-from-turkey

[75] Extending the European Hydrogen Backbone: A European Hydrogen Infrastructure Vision Covering 21 Countries (2021), Guidehouse, https://gasforclimate2050.eu/sdm_downloads/extending-the-european-hydrogen-backbone

[76] https://www.reuters.com/article/tap-hydrogen-study-idUKKBN28J2EH

TAP is a 48-inch diameter pipeline with initial natural gas throughput capacity of 10 bcm/year, which is fully booked for the first 20 years. Subject to an ongoing market testing process, consideration is being given to increasing natural gas capacity to 20 bcm/year by adding additional compressor stations.[77] Conversion to 100 per cent hydrogen service would require redesign of the compression system, and is unlikely to be possible while the pipeline continues to be booked to carry natural gas.

7. Summary & Conclusions

Turkey's energy policy is driven mainly by a desire to decrease reliance on imported energy. To that end, decarbonisation has not been an important objective, and Turkey has only just ratified the Paris agreement, but not yet updated its NDC. Indeed, the share of coal fired generation has been increasing despite the resulting increase in CO_2 emissions.

Turkey already has a high share of renewable power generation, from hydro, solar and wind, and has plans to increase generation capacity of all of these significantly over the coming years. The latest solar PV auctions have resulted in power prices of around 2 USc/kWh so that Turkey is well placed for low-cost renewable power generation. The first nuclear power plant is coming onstream in 2023, but the output of this plant is most likely to be used for baseload power generation.

Domestic natural gas production from the Sakarya field is due to start by 2023, producing up to 15 bcm/year, but there will still be a need for imports of natural gas to meet total demand in the range 40 to 50 bcm/year.

Turkey is considering hydrogen production from domestic sources primarily as a way to decrease its reliance on imported energy. Blue hydrogen is not a realistic option for Turkey (a) because it would increase the demand for imported natural gas and (b) there is very limited geological storage potential for CCS.

Green hydrogen is therefore the preferred route, particularly as the share of renewable power generation increases further. Currently, however, green hydrogen is much more expensive than the fossil fuel alternatives, despite the low cost of renewable energy.

As a first step, Turkey is considering blending low carbon hydrogen into the natural gas grid and tests have been demonstrating the technical feasibility at various levels up to 20 per cent blend. (20 per cent by volume, equivalent to around 7 per cent by energy content). It is feasible, subject to further technical checks, that this blend level could be introduced in some regions of the gas grid by 2030.

Turkey is expected to produce a hydrogen strategy later in 2021. Key points which a comprehensive strategy will need to address include:

- Fit of hydrogen production into broader decarbonisation and energy policy objectives;
- Incentives to stimulate low carbon hydrogen production;
- Incentives for existing industrial hydrogen users (refining and petrochemicals) to switch to low carbon hydrogen;
- Regulations and incentives for blending hydrogen into natural gas networks
- Potential longer term plans for Turkey to become an exporter of green hydrogen to Europe, probably by converting some existing natural gas infrastructure, like the TAP line.

[77] https://www.argusmedia.com/en/news/2214707-tap-details-gas-capacity-expansion-plan