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February 2020

The role of Portuguese gas infrastructure in the decarbonisation process

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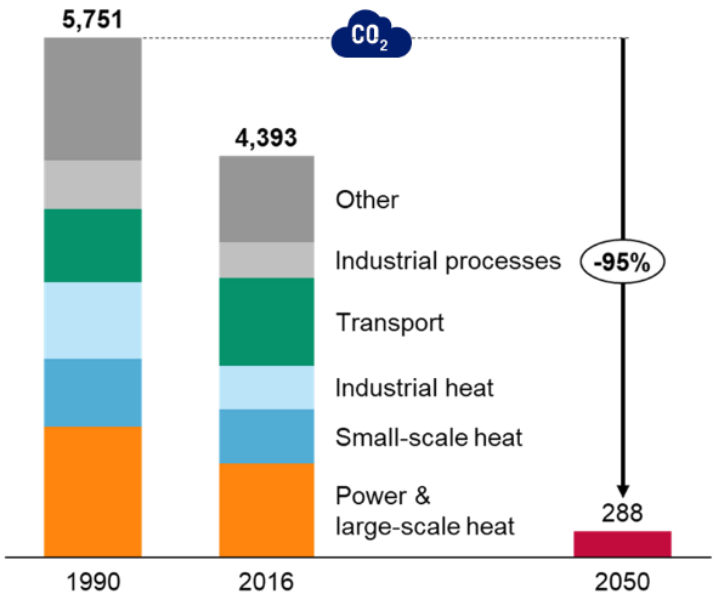
1. THE SCALE OF THE DECARBONISATION CHALLENGE

To achieve the Paris Agreement's 1.5ºC objective, Europe will need to implement a 95% economy wide reduction of its emissions by 2050 relative to 1990. Such an ambitious reduction requires a full decarbonisation of the energy sector (transport, heat and power) alongside a significant reduction in other sectors (shipping, aviation, agriculture, food, other land use and waste).

Figure 1 – The scale of Europe's decarbonisation challenge ($MtCO_2e$)



Source: National greenhouse gas inventories submitted to the UNFCCC by EU-28 Member States, Norway and Switzerland.

In November 2016, the Paris Agreement[1], an international agreement governing the mitigation of greenhouse gas emissions, entered into force. With more than 150 countries ratifying the agreement – including the three largest greenhouse gas emitters: China, the US[2] and India – there appears to be a very broad consensus across the globe that significant action is required urgently.

The main goal from the Paris Climate Change Conference (COP21) is to limit global warming to "well below 2ºC" compared to pre-industrial levels and pursue efforts to limit the temperature increase to 1.5ºC.

As a result of the Paris Agreement, governments have taken measures to tackle climate change, reduce emissions and to limit global warming as per the

[1] The main input for the Paris Agreement was the IPCC Fifth Assessment Report published in 2013 which alerted of the clear effect of human influence on climate change.

[2] In November 2019 the US formally notified the United Nations of its withdrawal from the Paris Agreement, which will take a year to complete.

targets set by the Paris agreement. As an example, by mid-2019 fifty-seven carbon pricing initiatives around the world were implemented – or scheduled for implementation[3].

Although Europe is seen as the leading region in the fight against climate change, other countries are also implementing significant measures. In particular, China, the current largest greenhouse gases (GHG) emitter with around 27% of total CO_2 worldwide emissions[4], is undertaking measure to mitigate climate change:

- As part of the Paris Agreement, China has set a target for CO_2 emissions to peak by 2030 and increase its share of non-fossil fuels in total primary energy to 20% by 2030[5].
- In 2018 it commissioned the 18th world largest Carbon Capture & Storage (CCS) facility[6], and has more than 20 CCS projects in various stages of development.
- The National Alliance of Hydrogen and Fuel Cell[7] was established in 2018 to promote the development and use of hydrogen, particularly in transportation.

In the US, although the federal government has recently announced withdrawal from the Paris agreement, many initiatives are happening at state and local scale. In particular California has set binding targets for economy-wide carbon neutrality by 2045, with at least 60% of its primary energy coming from wind and solar technologies and the remaining from other renewable sources and zero carbon gases.

In Europe, it is widely accepted that achieving the 1.5ºC objective requires to reach at least a 95% economy-wide reduction by 2050 relative to 1990 in the Union. In AFRY's opinion, such an ambitious reduction practically implies the full decarbonisation of the energy sector (i.e. transport, heat and power generation), so that the remaining 5% emissions remain in other sectors where full decarbonisation will be much harder to achieve – i.e. in shipping, aviation, agriculture, food, other land use and waste.

In order for the Paris Agreement long-term goals to be met, the Agreement requires for each Party to establish Nationally Determined Contributions (NDCs)[8], which embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The European Union's NDC under the Paris Agreement is to reduce GHG by at least 40%[9] by 2030 compared to 1990 levels. This has been set as part of its wider 2030 Climate and Energy

[3] World Bank - State and trends of carbon pricing 2019

[4] Our World in Data – CO2 and Greenhouse Gas Emissions

[5] Climate action tracker – Pledges and targets

[6] China establishes world's 18th large scale CCS facility – ibj online

[7] China hydrogen alliance

[8] The next NDCs are to be submitted by 2020, and every five years after.

[9] The European Green Deal published on 11 December 2019 points towards increasing this target to 50/55%.

Framework, where the EU has also set an objective of at least 32% share of renewable energy by 2030 and at least 32.5% improvement in energy efficiency.

In line with the Paris agreement, Europe's ambition goes beyond 2030[10], and in December 2019 the EU presented the European Green Deal, aiming at creating a fair, competitive and carbon neutral society and economy within Europe by 2050; it was adopted by the European Parliament in January 2020. As far as GHG emissions are concerned, it mentions the option of implementing carbon border adjustments to mitigate the risk of carbon leakage and of the loss of competitiveness. It also insists on the need to decarbonise the electricity generation sector, in particular phasing out coal plants and fostering zero-carbon gases. To finance its Green Deal, the EU presented in January 2020 an ambitious budget of at least €1 trillion for investments in the 2020-2030 decade, leveraging on EU budget and associated instruments (for instance InvestEU) to attract private investment.

To achieve the European Union's overall target, Member States must develop their own strategy based on the particularities of their industry and energy system, which is to be submitted to the European Commission through the "Integrated National Energy and Climate Plans" (NECP). EU governments presented the first versions of their NECP in 2018; from the Commission's feedback on these draft plans, governments were due to present updated versions of their NECP by end of 2019, although some countries are already delaying their contribution to early 2020.

In this context, Portugal has not only developed its NECP for 2030, but extended its vision to 2050 through the publication of the "Roadmap for Carbon Neutrality 2050" (RNC2050).

Figure 2 – Portuguese long-term decarbonisation strategy

	2030	2040	2050
GHG reduction[1]	-45/55%	-65/75%	-85/90%
Renewable penetration[2]	47%	70/80%	85/90%
Energy efficiency	35%	-	-
Interconnections	15%	-	-

Source: NECP and RCN documents.

[10] November 2018 the Commission presented the "European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by 2050".

Both documents show a strong commitment to the electrification of the transport sector through electric vehicles. However, green hydrogen is also expected to play an important role for the decarbonisation of both transport and heat: recently the Portuguese government has publicly expressed its ambition for the development of a green hydrogen economy in the country, taking advantage of its privileged wind and solar resource. Additionally, the latest version of the Portuguese NECP emphasizes the role of renewable gases during the energy transitions.

The energy transition will open a range of possibilities for the different industries to develop net-zero emission technologies. In 2018 AFRY demonstrated in its Full Decarbonisation Study[11] that, in order to make the decarbonisation of the energy sector a reality across Europe, the growing electrification of the economy must be accompanied by the development of zero-carbon gases solutions – green hydrogen, blue hydrogen with CCS, CCS gas and biomethane. To support the energy transition and to fully integrate these new zero-carbon gas solutions, the European gas infrastructures are critical; in particular they will allow flowing natural gas to gas-fired plants to cope with the decommissioning of coal plants across Europe during the transition. Beyond the transition, gas networks will be needed to transport and distribute zero-carbon gases in the decarbonised economy.

AGN, as the Portuguese association of natural gas companies, is committed to guiding the gas industry efforts and actions throughout the energy transition, towards a net-zero emission economy in Portugal. **AGN is willing to identify the best solutions for the Portuguese gas industry to be a key player in the decarbonisation of the Portuguese energy industry.**

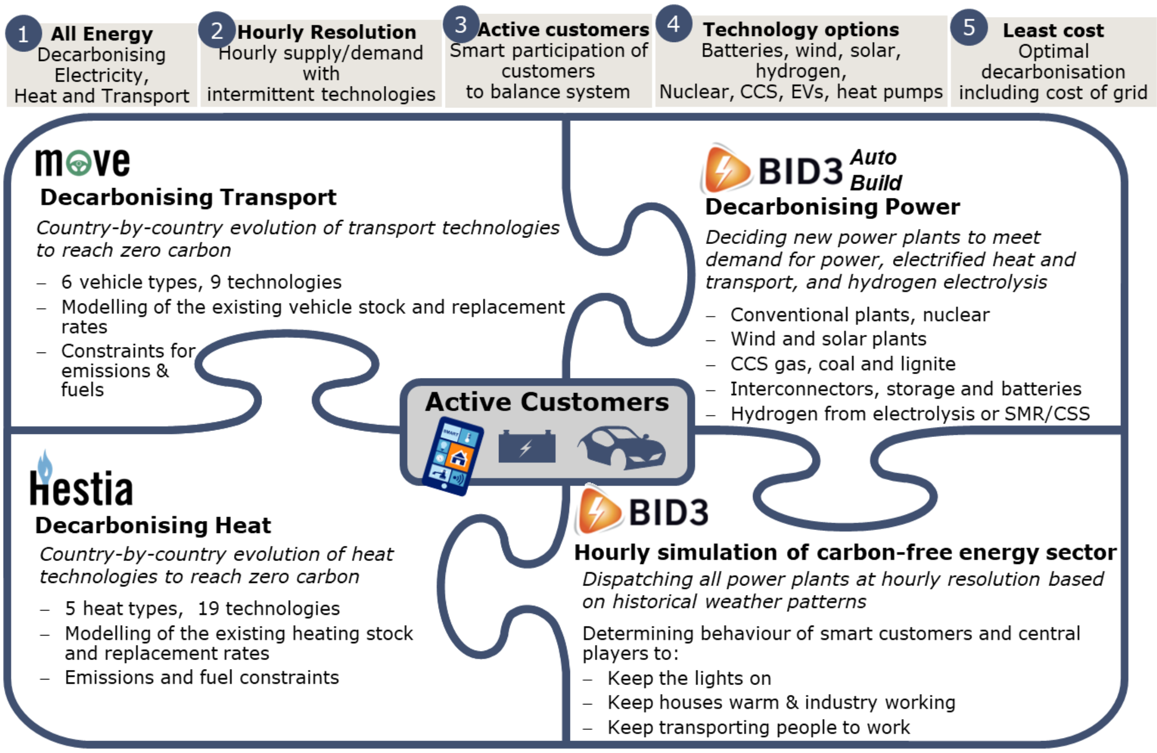
In this context, this report prepared for AGN serves as a guide for the Portuguese gas industry, and in particular the owners and operators of distribution networks, to understand how they can contribute to the efficient decarbonisation of the Portuguese energy sector (defined in this study as power, heat, and rail and road transport), and help achieve the European objective of net-zero emissions by 2050.

[11] https://www.poyry.com/news/articles/fully-decarbonising-europes-energy-system-2050

2. IMAGINING A ZERO-CARBON ENERGY SECTOR

AFRY has developed a whole model suite of the energy sector to quantify the benefits of allowing competition amongst the different technologies available to achieve a zero-carbon energy sector by 2050. The modelling environment has been set up to allow for interaction between the different models.

Figure 3 – AFRY decarbonisation modelling suite



For the purpose of this study we imagine a fully decarbonised energy sector by 2050 across Europe, including Portugal – the energy sector consisting of power generation, heat, and road and rail transport. We explicitly do not consider the decarbonisation of other sectors, such as industrial processes, agriculture, waste, navigation and aviation; these sectors are outside the scope of this study.

In order to be in line with the ambitious reduction target for the whole European economy amounting to -95% emissions relative to 1990[12], we achieve a 100% decarbonisation of the energy sector, allowing for a 85%

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[12] We have set the economy-wide target for our study period at 95% relative to 1990, which is the upper end of the range of the EU's reduction objectives, as expressed in the European Commission's Communication "A Roadmap for moving to a competitive low carbon economy in 2050" – COM(2011) 112 final. More recently, on the 11 December 2019 27 member states of the European Union agreed in principle to the 'Green Deal' which commits them to a net-zero carbon economy by 2050, increasing the challenge in the non-energy sector.

decarbonisation of the non-energy sectors (industrial processes, agriculture, etc.), as we acknowledge that these are much more difficult to decarbonise.

If it were assumed that these other sectors could not achieve the 85% decarbonisation required, the energy sector would need to deliver more than 100% decarbonisation, through negative emissions, mainly using bioenergy in CCS installations. This has not been considered in this study.

The pathway developed for AGN aims at representing a future where the gas industry has been able to adapt to the requirements from decarbonisation and contributes in several ways to the decarbonised energy sector in 2050 and beyond[13]. In order for this pathway to be viable, the gas industry needs to provide significant quantities of hydrogen and biomethane, as well as a CCS network and storage facilities. Some of the principles followed for this pathway are:

- **Gas networks are utilised**: Rather than abandoning gas networks that are in place in Portugal, this pathway aims to find ways of decarbonising these networks and so reduce the level of peak electricity grid expansion that would otherwise be required. This can be achieved by a combination of injecting biomethane in some parts, and converting other parts of the grid to carry hydrogen. This is particularly relevant in Portugal where the young age of most of its gas network means it can easily be reconverted for the use of hydrogen.
- **Decarbonisation determined by economics**: The choice between the large range of technologies available is mainly based on long-term economics. While many technologies are technically available in the pathway, not all of them will be featured in the result, as they are economically unattractive compared to others.
- **Overall full decarbonisation of Europe's energy sector**: AFRY's decarbonisation model suite is restricted to meet European decarbonisation targets by 2050 and not individual NECP targets. However, given that the final NECP for Portugal has been recently published, AFRY has taken into account major targets from this document.

One of the key strengths of AFRY's decarbonisation modelling suite is that it co-optimises gas and electricity networks – this is particularly relevant in Portugal, where the modern gas networks can be easily converted to hydrogen, avoiding stranded assets and mitigating the risk of excessive expansion of the electricity grids – which represents an important share of the total cost of decarbonisation.

The programme of work for the study was structured into three workstreams, each covering one sub-sector of the Portuguese energy sector:

- Transport analysis workstream. The transport workstream has analysed the Portuguese transport sector, considering the transition towards a zero-emissions world in 2050. This analysis was based on the current stock of vehicles and expected technology cost, capability and availability.

[13] Pöyry Point of View - Fully decarbonising Europe's energy system by 2050.

- Heat analysis workstream. In the heat workstream, the transition towards a zero-carbon system for all sectors of heating – residential, commercial and industrial – has been assessed. The basis for this analysis was the current heat supply and expected technology cost, capability and availability.
- Power analysis workstream. All analysis is combined in the power workstream. This model uses the outputs from the other workstreams and iterates amongst the models in order to analyse the total demand for electricity in Portugal. The hourly pan-European modelling was based on a database of every power plant in Europe, detailed hourly profiles for demand, temperature, weather, wind speeds, solar radiation, EV charging, and electric heating, as well as assumptions for future technology cost, capability and availability.

The decarbonisation path towards a zero-carbon energy sector in 2050 follows a trajectory that is partly informed by the provisions of the two main EU-level climate instruments, the EU Emissions Trading System (EU ETS) and the Effort Sharing Decision (ESD), as well as its successor, the Effort Sharing Regulation (ESR).

3. PORTUGAL'S ZERO-CARBON ENERGY SECTOR

AFRY has developed a whole model suite of the energy sector to quantify the benefits of allowing competition amongst the different technologies available to achieve a zero-carbon energy sector by 2050. The modelling environment has been set up to allow for interaction between the different models.

Figure 4 – Key results of the pathway developed for AGN

The AGN pathway represents a future where economics determine which technologies are deployed in order to fully decarbonise the energy sector. The gas industry choses and is allowed to adapt to a decarbonised system and provides zero carbon energy in all sectors.

Transport

Electric vehicles dominate in lighter segments while fuel cell vehicles are a more economical alternative in heavier transport segments.

Heating

Boilers, heat pumps and hybrid systems play an important role in utilising biomethane and hydrogen. CCS installations are used were necessary for process emissions. District heating networks are retained and decarbonised.

Power generation

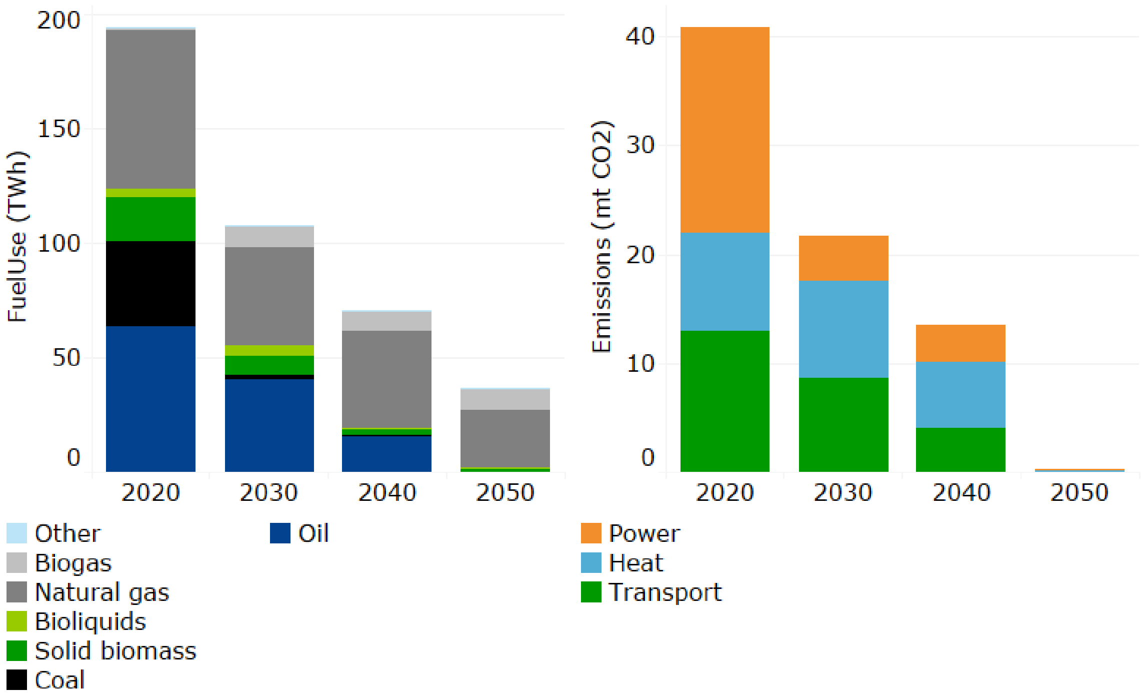
While renewable sources account for the majority of capacity, they are balanced mainly with CCS plants using natural gas as fuel.

Smart networks

Power networks allow demand side response. Many gas distribution networks convert to hydrogen. A CO_2 network is established to transport CO_2 to offshore storage sites.

In the pathway developed by AFRY for AGN, fuel consumption decreases quickly as coal and oil disappear from the system. Emissions decrease accordingly, mainly in the power sector were the rapid closure of coal plants allows to quickly mitigate emissions during the first decade.

Figure 5 – Total fuel consumption and total emissions by sector in Portugal – pathway developed for AGN



Note: Fuel consumption only includes input fuel. Does not include use of electricity or hydrogen

3.1 Transport in the AGN pathway

The transport sector gradually transitions from an almost exclusively oil-based sector towards a largely electric passenger segment and a hydrogen-based heavy freight segment.

In passenger vehicles, internal combustion engines continue to dominate until 2030. After that, most of the car segment converts to fully electric vehicles, while buses start using hydrogen. By 2050, all passenger transport is fuelled by either electricity or hydrogen.

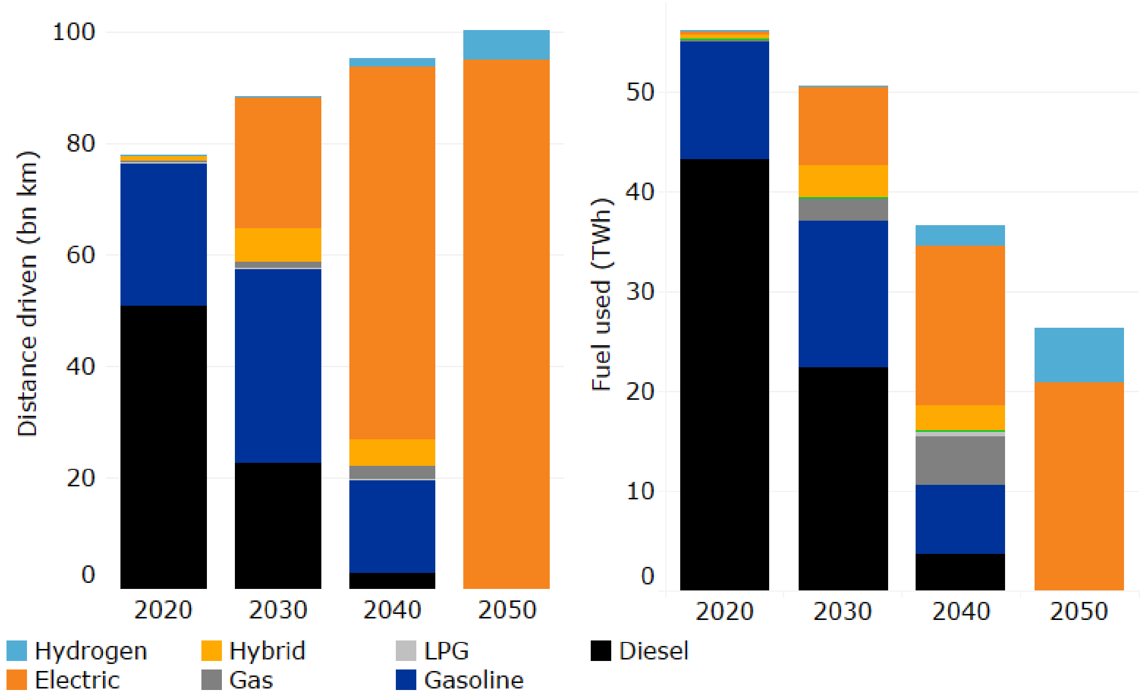
In the light truck segment, hybrid and electric vehicles start to replace diesel and gasoline from the 2020s onwards. Heavier freight transport segments start taking advantage of hydrogen, once this option becomes available by 2030.

Overall fuel consumption in the transport sector declines substantially, as electric and hydrogen vehicles are more efficient than diesel and gasoline alternatives, when calculated on the basis of tank-to-wheel[14].

Other fuels play a minor role in the pathway; small amounts of LPG vehicles are used in the freight segments. However, by 2040, most of these fuels have disappeared.

[14] Describes the use of fuel and emissions during driving.

Figure 6 – Kilometres driven and fuel demand per fuel mix in Portugal – pathway developed for AGN



3.2 Heat in the AGN pathway

In the heating sector, there are a greater number of technologies available – this increased choice leads to a shift from current heating methods. At present, Portugal relies on natural gas for a majority of both space and process heating. While unabated natural gas is not available in 2050 due to the emissions restrictions, the pathway developed for AGN seeks to optimise the utilisation of current infrastructure by utilising mostly hydrogen, but also using biomethane and CCS where reasonable to do so.

A key message from this pathway is that it identifies a continued role for gas technologies, either natural gas associated to CCS, biomethane or hydrogen; by 2050, zero-carbon gases remain the most relevant fuels for heat production in this pathway, due to the great deployment of hydrogen.

Non-process sector (residential and commercial space and water heating)

Results in Figure 7 show that electricity becomes rapidly the most important fuel in the non-process heat sector. Portugal's mild weather facilitates the early deployment of air-source heat pumps, while hybrid heat pumps using hydrogen are later deployed in the 2040s to substitute a portion of gas boilers.

By 2050, almost all of non-process heat is provided by electricity together with a small amount of hydrogen. Air-source heat pumps and hydrogen hybrid heat pumps are the preferred appliances with a small number of ground-sourced heat pumps and hydrogen boilers which help complete the transition.

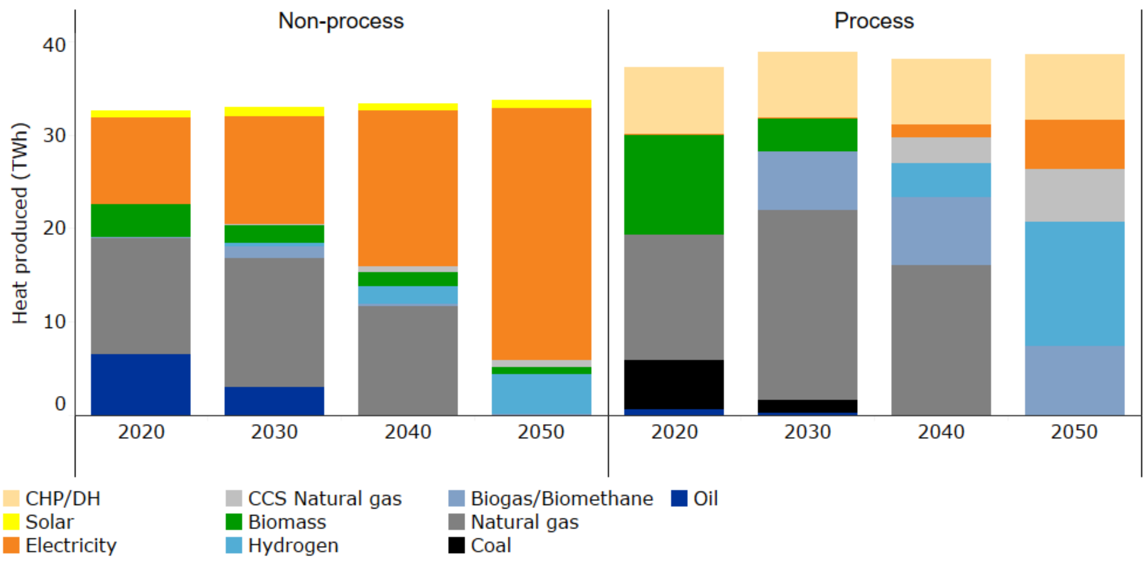
Process sector (industrial heat)

Figure 7 also shows the transformation in the process heat sector along the AGN pathway. With limited technology options available to meet the specific temperature requirements of process heat, the options available in the future years are more straightforward. The higher temperature heating requirements mean that the hybrid heat pumps, deployed in the non-process sector, are no longer suitable. This leads to large scale roll-out of hydrogen and biomethane boilers, and a lower proportion of CCS natural gas.

Initial reductions in CO_2 emissions are achieved by switching away from carbon intensive coal and oil boilers. This switch sees the majority of these technologies taken off the system by 2030 and completely removed by 2040. These technologies are replaced initially by gas boilers, and later by hydrogen. By 2040 the CO_2 constraints mean that CCS has to be introduced to mitigate the emissions from the natural gas boilers and emissions from the process themselves to ensure decarbonisation. The potential for introduction of CCS in Portugal has been carefully analysed and is explained further below.

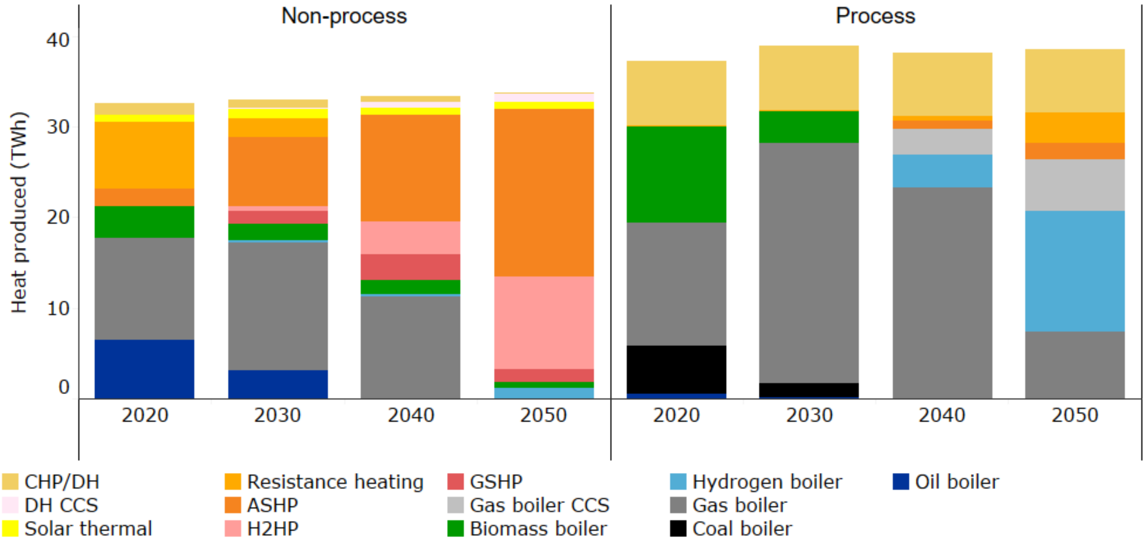
The residual demand is met with CHP, which is mostly gas-fired CCS, and a small amount of electricity in lower-temperature processes.

Figure 7 – Heat production per fuel in Portugal – pathway developed for AGN



Note: AFRY defines non-process heat as heat used for space heating, and process heat as heat used in industrial processes

Figure 8 – Heat production per appliance in Portugal – pathway developed for AGN



Note: AFRY defines non-process heat as heat used for space heating, and process heat as heat used in industrial processes

Potential for the use of Carbon Capture and Storage (CCS) in Portugal

CCS is a proven technology that is currently under development in multiple projects around the world:

- In Norway, there are several examples of existing and planned large-scale CCS facilities; Equinor has 20-year experience in capturing and storing more than 20 million tonnes of CO_2 to date at Sleipner and Snøhvit, and Gassnova is developing a large-scale deployment project[15] that will be capturing CO_2 from a cement manufacturer, ammonia producer and a waste-to-energy plant and storing the CO2 in the Norwegian North Sea.
- Multiple oil and gas supermajors are promoting CCS as part of their transition strategies for moving to a lower carbon economy, e.g. Shell Sky scenario[16].

Additionally, the IEA consistently reports that CCS is a pre-requisite for large scale decarbonisation in industry and power generation[17].

As a result of the latest evidence, AFRY has reflected in its latest Hydrogen pathways[18] the expectation that CCS costs will be lower than originally assumed.

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15 Gassnova and Gassco. "Feasibility study for full-scale CCS in Norway." 2016.

16 https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

17 IEA - Transforming industry through CCUS

18 https://www.poyry.com/news/articles/utilising-versatility-hydrogen-fully-decarbonise-europe

However, in spite of the current support for CCS, AFRY acknowledges that there are various barriers that need to be mitigated in order for this technology to be deployed at scale in a specific country. To name a few:

- Financing CCS development (regulated / non-regulated business): For this study we consider that the necessary finance will enable the delivery of CCS. However in reality this is a current barrier. As a result there needs to be a coordinated approach between government, European Commission initiatives and the private sector to ensure CCS becomes a technology that can be delivered at scale and one that is treated as 'business as usual' in the energy sector. This coordinated approach may include direct private financing, regulated networks or a combination of both.
- Incentives and support: The development of CCS will be predicated on the appropriate support regimes and structures being in place. For example this may include changes to the tax regimes to support the wider development of a CCS industry. In addition, it is likely there is a need for direct project support for early CCS projects. UK can be seen as an example of incentive and support, where despite there being several delays in the development of CCS projects, government support has been key in the progress of these projects under its clean growth strategy action plan[19].
- Convincing all EU countries to establish a new network: The deployment of CCS is dependent on the creation of an European network to transport and store CO_2, as it is assumed that all CO_2 produced this way is stored in depleted gas fields in the North Sea, including fields in Norwegian, British and Dutch territories or in more local and suitable aquifers if they are available. Whether all countries choose to adapt and allow CCS to be part of this future will depend on how successful the gas industry is in lobbying and the openness of stakeholders.
- CCS network configuration: Although not considered as part of this study, there will need to be significant coordination between industry and governments in order to ensure that economies of scale[20,21] are realised, especially in regard to the transport and storage of CO_2. These economies of scale and lowering risk profile are vital to ensure cost reductions and make CCS technology competitive with other low carbon technologies.

Of particular relevance when analysing Portugal is the need for economies of scale to appear in order to lower the risk profile of CCS and to ensure cost reductions mainly related to transport and storage. Although AFRY assumes that the remaining barriers are effectively mitigated, for the development of the AGN pathway we have been able to further analyse the industry, and this

[19] Clean Growth, The UK Carbon Capture Usage and Storage deployment pathway - An Action Plan, 2018.

[20] This view on the importance of economies of scale is also reflected in the 'CCS Cost Reduction Taskforce Report'. This report suggests that there is a significant opportunity for reductions in the unit costs of both transport and storage through the development of a CCS hub (or cluster).

[21] The UK Carbon Capture and Storage Cost Reduction Task Force. "CCS Cost Reduction Taskforce – Final Report." 2013.

has led us to believe that economies of scale will be more difficult in Portugal, thus, making hydrogen more competitive than CCS.

The result of this analysis is that CCS will only be deployed in industries where this technology is necessary for the decarbonisation of process emissions, as there is currently no other alternative to decarbonise all of these emissions[22]. This will create small economies of scale in certain areas, amounting to a potential 10% of total gas demand to be converted with CCS.

3.3 Power generation and hydrogen production in the AGN pathway

The electrification of heat and transport, as well as the production of hydrogen from electrolysis, lead to a significant increase of electricity demand over time.

The overall amount of installed generation capacity in Portugal more than doubles during the studied period, from 21GW in 2020 to 50GW by 2050. Between 2020 and 2030 there is a rapid deployment of solar PV as its costs decrease rapidly; then from 2030 until 2050 installed capacity of both solar PV and onshore wind increases significantly, reaching 22GW and 17GW respectively by 2050. Hydro, pumped storage and CHP remain stable across the studied period. The remaining firm capacity in 2050 is provided by a small amount of gas-fired power plants associated to CCS.

Total electricity generation volume increases accordingly between 2020 and 2050. By 2050, more than 95% of power generation comes from renewable sources, with the majority of it being produced by wind and solar PV facilities.

Hydrogen demand is covered through a mix of electrolysis and steam methane reforming (SMR). SMR is available from 2030 onwards and increases rapidly between 2030 and 2040, remaining stable until 2050 as electrolysis becomes available by 2040, and alongside the continued high levels of RES deployment it then provides a more cost-efficient way of producing hydrogen. Emissions from the production of SMR in 2050 are mitigated with CCS.

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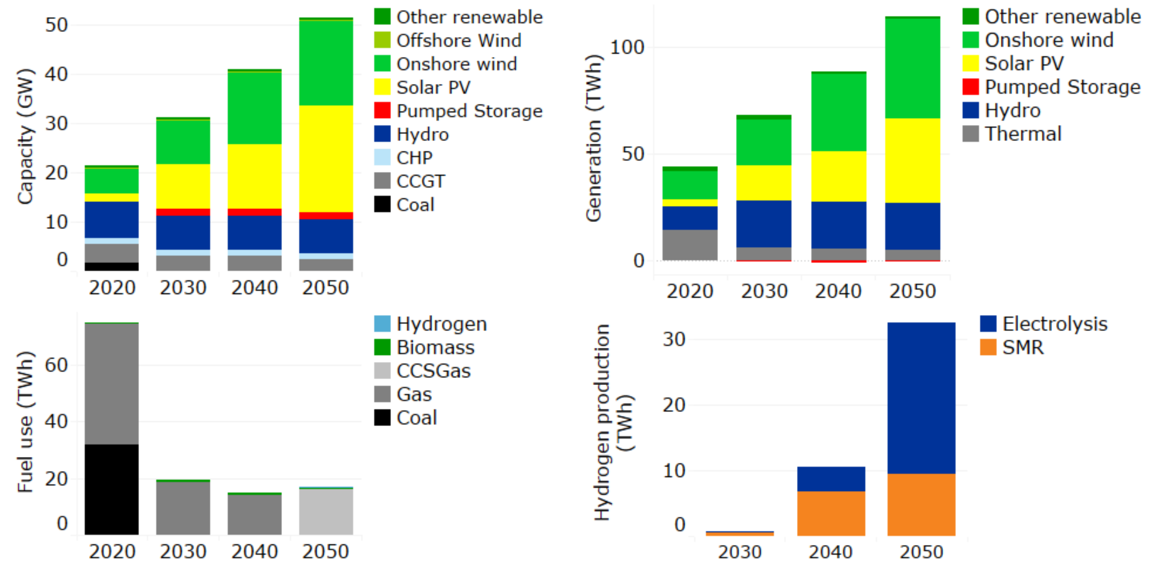
[22] There may be some new technologies and/or chemical process changes but for many industries these are not anticipated to cover all CO_2 emissions from industrial processes.

Figure 9 – Capacity installed, generation, fuel used and hydrogen production in Portugal – pathway developed for AGN



3.4 The savings of the pathway developed for AGN compared to an 'all-electric' pathway

AFRY and AGN have investigated a pathway where gas infrastructure in Portugal is preserved to allow zero-carbon gases to compete in the transition to a decarbonised energy sector. The alternative to this pathway would entail assuming that only electrification can achieve decarbonisation, and policies are enforced to prevent the development of zero-carbon gas alternatives, resulting in new nuclear and biomass build[23]. However, according to AFRY's analysis, this would imply significant extra costs.

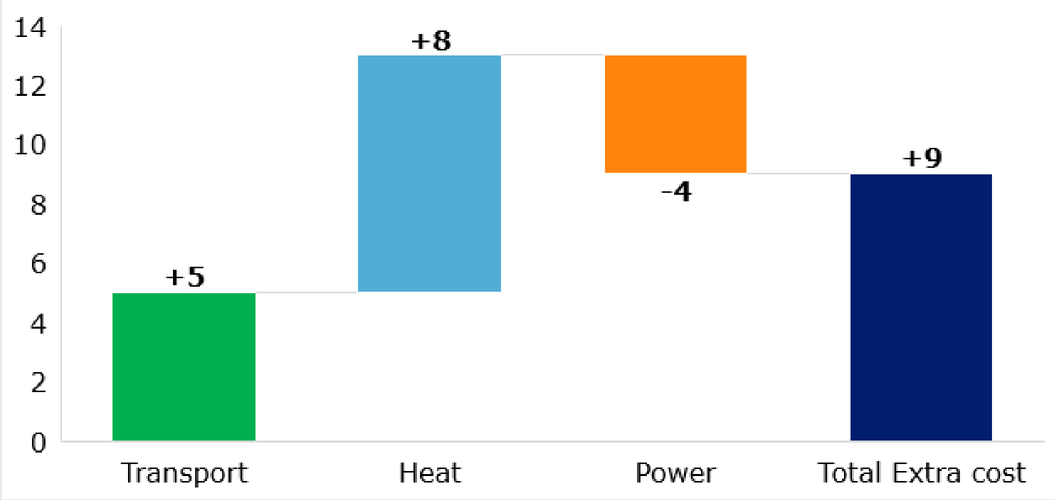
AFRY has combined the analysis from all sector models with calculations of networks, supply and other costs to produce the total system costs of each pathway[24,25]. The total cost difference is shown in Figure 10.

[23] This pathway was explored for Europe in AFRY's Point of View.

[24] Calculated in NPV terms using a social discount rate of 4%

[25] In order to understand the costs of the alternative pathway, the 'All Electric' pathway, AFRY has used the results for Portugal from its European decarbonisation study.

Figure 10 – Extra costs of an 'all-electric' pathway compared to AGN pathway (€bn, NPV)



The largest difference can be seen in the heat sector, where the absence of CCS, biomethane and hydrogen under an 'all-electric' pathway results in the installation of costlier heat appliances. In the transport sector, the extra cost of the 'all-electric' pathway corresponds to the electrification of Heavy Goods Vehicles (HGVs), less competitive than hydrogen. In the power segment, although the higher level of electrification in an 'all-electric' pathway implies a further expansion of the power grid, the operation of two separate networks and supply chains (electricity and gas/hydrogen) in the AGN pathway ends up with higher costs.

Eventually, the decarbonisation of the Portuguese energy sector following an 'all-electric' pathway would entail an extra cost of €9bn over the whole period when compared to the pathway developed for AGN.

4. ROADMAP FOR PORTGUESE GAS DISTRIBUTION NETWORKS

The results of the pathway developed for AGN show that zero-carbon gases should play an important role in a decarbonised Portuguese economy – not only during the transition, but also once it has fully materialised. That is the reason why Portuguese gas distribution infrastructures need to prepare for a future where different types of zero-carbon gases coexist.

Very often discussions focus on electrification as the natural path towards decarbonisation, and assume that the role of gas(es) will be mainly during the transition. However, this study finds that there are several ways that gases – and especially zero-carbon gases – can make the decarbonisation process of the Portuguese energy sector much more efficient, and play a key role after the transition, in an established decarbonised economy.

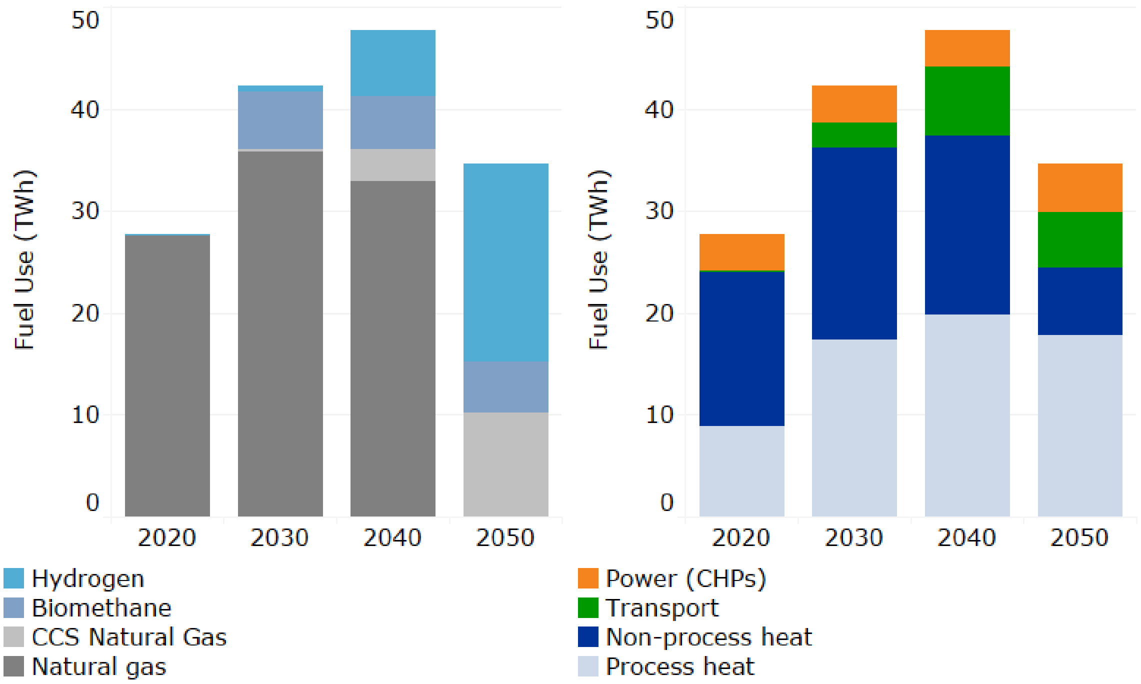
Zero-carbon gases include:

- Hydrogen: Hydrogen could be used in all three energy sectors but is most beneficial in heavy transport (where size and weight restrictions for batteries make electricity uneconomical) and space heating (when electrical heat pumps require back-up for cold weather). Hydrogen also competes with CCS in industry and power generation. In Portugal, it will be mostly produced from electrolysis, as abundant renewable resources make this cheaper than SMR.
- Biomethane: Straightforward in its use both in industry and buildings, and available in significant quantities, biomethane could be a quick-win for the gas industry in Portugal. It appears that biomethane is most beneficial to be used in the heat sector, both for process and non-process heat. Biomethane can also help to off-set residual emissions in other sectors (e.g. back-up power generation, hydrogen production) that otherwise would be very expensive to avoid, by being burnt in CCS installations, and thus creating negative emissions.
- Natural gas associated to Carbon Capture and Storage (CCS): the availability of CCS is a critical requirement to establish a zero-carbon gas industry, since biomethane alone only accounts for a fraction of gas demand, and hydrogen production from methane reforming requires carbon capture in order to be considered zero carbon. Furthermore, CCS will be needed to decarbonise non-energy sectors, such as industrial processes.

Focusing on Portuguese gas distribution networks, the main results of the pathway developed for AGN have shown that the medium- and low-pressure grids[26] will be key in the decarbonisation of the energy sector, and continue to play a relevant role when it is achieved by 2050, as shown in Figure 11.

[26] Gas distribution networks in Portugal are those operated at pressures below 20bar.

Figure 11 – Evolution of energy demand from gas distribution networks in Portugal by fuel type and by sector



Note: Only includes input fuel. Does not include use of electricity or hydrogen

Indeed, AFRY projects that energy demand from gas distribution networks[27] will peak in 2040, playing a key role in the decarbonisation of the economy. Additionally, energy supplied by these networks is expected to be 25% higher in 2050 than 2020 natural gas demand (in TWh).

Looking at the sectors underlying energy demand from gas distribution networks, the decarbonisation of heat production will be the main driver of its evolution:

- By 2030, gas demand for process heat increases strongly, as gas boilers are replacing gradually oil and biomass ones in industrial appliances. Although most of this demand will be sourced with imported natural gas, by then the injection of biomethane into the networks represents 13% of the volume supplied.
- By 2040, hydrogen represents a relevant share of the energy supplied from the distribution grids, 14%, and most (70%) of hydrogen volumes are supplied by SMR plants while electrolysis capacity is developing. Hydrogen is consumed equally amongst transport, process and non-process heat appliances. This implies that distribution networks are able to transport hydrogen, either in new dedicated networks, in existing ones fully reconverted to hydrogen, or mixed with natural gas and/or biomethane (only possible for heat appliances).

[27] AFRY has assumed that the split between distribution and high pressure networks in industrial heat and CHP segments remains constant in the future at 2018 levels.

- By 2050 some industrial clusters using CCS as well as CHPs will be able to continue using natural gas; the remaining demand will be covered by hydrogen, or – to a lesser extent – by biomethane. Hydrogen delivered through distribution grids exceeds 20TWh, of which more than 72% comes from electrolysis plants.

In order for this pathway to become a reality, gas distribution networks need to anticipate these changes and make investments to be technically prepared to play their role in the decarbonisation process. We highlight below the key requirements to have networks prepared for zero-carbon gas solutions:

- **Hydrogen**: in order to understand what it takes to convert existing gas networks to hydrogen, it is relevant to look at the H21 North of England Project, which aims to convert 13% of Great Britain gas demand to hydrogen. Some of the main challenges identified in these projects are:
  - upgrading current network mainly made of iron and steel pipes to modern polyethylene pipes, as they are convenient to transport hydrogen;
  - the conversion of end-users' appliances – mainly boilers and burners – so they are ready to burn hydrogen instead of gas;
  - ensuring that there is a sufficient volume of hydrogen available at any moment during the conversion to guarantee the security/continuity of supply;
  - detailed plan – work so far has been at a higher level so a detailed implementation plan needs to be developed for approval, with a request for government investment alongside the three current investors; and
  - financing – where it is recommended that the costs of conversion to hydrogen at both network and consumer levels would be included with the network company asset base under the regulated returns, keeping the costs as low as possible.

  In the Portuguese case, where all gas distribution networks are made of polyethylene – with the exception of some remaining kilometres of iron and steel pipe in Lisbon that are due to be fully replaced by polyethylene by 2022 – the first big challenge does not exist. So the focus of investment planning for network operators shall be on the progressive conversion of end-users' appliances, guaranteeing as much as possible the continuity of supply, and ensuring that hydrogen supply capacity to the grid is enough to supply converted networks. This means the conversion plan must be in line with the commissioning schedule and location of hydrogen producing facilities (electrolysis plants, SMR plants) across the country.

- **Biomethane**: the main challenge when supplying a gas distribution network with biomethane instead of natural gas is related to the injection of the biomethane to the network as it can be spread all across the territory; that means networks should be ready to accommodate multiple injection points and deal with potential gas quality issues; on end-users' side, no changes are required.

- **Natural gas associated to CCS**: in this study we have considered that the use of CCS with natural gas would be limited to industrial clusters where CCS facilities should be developed in any case to mitigate process emissions; so the investment needed from a gas distribution network operator perspective would need to be agreed with industrial consumers in order to develop CCS facilities able to capture both heat and process emissions.

AFRY has analysed Portugal's gas distribution infrastructure based on data provided by AGN. As explained in Chapter 3, we understand that the potential for CCS is limited to those areas where process emissions need to be mitigated with this technology, and so economies of scale appear for CCS, making it economical for a cluster of industries to also convert their heat production to CCS gas.

Using this approach, AFRY has analysed the potential for CCS penetration in Portugal and has identified the potential for CCS clusters in the districts of Viseu, Lisboa, Aveiro, Coimbra, Leiria, Porto, Setúbal and Santarém, since all these areas include industrial complexes where CCS will be needed to mitigate process emissions.

Additionally, where these CCS clusters appear there is also a potential for the use of biomethane, given the possibility to mix natural gas and biomethane in the same network. AFRY has split the use of available biomethane amongst these districts. The remaining demand is assumed to correspond to hydrogen.

AFRY has identified for each gas distribution system operator (DSO)[28] and district in Portugal the potential weighting of hydrogen, biomethane and natural gas demand in their network by 2050, as shown in Figure 12. All DSOs need to prepare for potential hydrogen demand either from industry or residential consumers; however, some of these networks also need to prepare to combine the delivery of hydrogen with natural gas in some areas – i.e. the CCS clusters.

If we take into account that hydrogen demand is expected to appear by 2030 and CCS by 2040, AFRY recommends that Portuguese DSOs start preparing for the deployment of zero-carbon gases in Portugal as soon as possible.

[28] AFRY has limited its analysis to the cases of the DSOs that belong to to Galp Gás Natural Distribuição Group and REN Portgás Distribuição, both members of AGN, and currently representing more than 99% of gas supplied from distribution networks.

Figure 12 – Hydrogen, biomethane and natural gas shares in the energy supply from distribution networks in 2050 – breakdown by DSO and district

DSO	District	% of demand		
		Hydrogen	CCS Natural gas	Biomethane
Beiragás	Castelo Branco	100%	-	-
Beiragás	Guarda	100%	-	-
Beiragás	Viseu	20%	20%	60%
Dianagás	Évora	100%	-	-
Duriensegás	Braganca	100%	-	-
Duriensegás	Vila Real	100%	-	-
Lisboagás	Lisboa	20%	10%	70%
Lusitaniagás	Aveiro	10%	60%	30%
Lusitaniagás	Coimbra	20%	10%	70%
Lusitaniagás	Leiria	20%	20%	60%
Medigas	Faro	100%	-	-
Portgas	Braga	100%	-	-
Portgas	Porto	20%	10%	70%
Portgas	Viana Do Castelo	100%	-	-
Paxgás	Beja	100%	-	-
Setgas	Setúbal	15%	36%	49%
Tagusgás	Portalegre	100%	-	-
Tagusgás	Santarém	20%	10%	70%

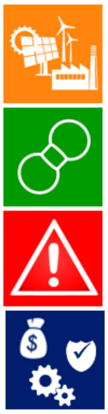
5. CONCLUSIONS AND RECOMMENDATIONS

The Roadmap for Carbon Neutrality in Portugal should be updated to reflect the clear benefits that come from repurposing gas distribution networks to support deployment of biomethane and hydrogen and CCS clusters where required.

The pathway prepared for AGN for the decarbonisation of the Portuguese energy sector shows that the transition can clearly benefit from positioning zero-carbon gases at the centre of the effort. The conversion of Portuguese gas distribution networks could save up to €9bn to the Portuguese economy when compared to a pathway where zero-carbon gases are not allowed and both transport and heat are going all-electric – with its massive use of biomass for high temperatures in industry, where there is no viable electric alternative to existing appliances.

Figure 13 shows AFRY's main recommendations to Portuguese policy makers to achieve these goals.

Figure 13 – AFRY recommendations to Portuguese policy makers



"Targets should be set for zero carbon gases levels in the energy mix so Portugal can take advantage of its privileged solar and wind resources"

"Portugal's abundant solar resource means hydrogen can be produced at scale and at the cheapest level across Europe"

"The re-purpose of the Portuguese gas network reduces the required expansion of electricity grids by half compared to an all electric scenario"

"Portugal is well placed to be at the forefront of decarbonisation as its modern gas network can easily be used and adapted to support biomethane and hydrogen deployment and CCS clusters, reducing the risks and costs"

Accordingly, in order for carbon neutrality in Portugal to become a reality, it is necessary to:

- **Prepare the transition from unabated to zero-carbon gases**: Nowadays, for many industrial heat appliances that require high temperatures there are no practical or economical electric solutions. This means that zero-carbon gases are needed to correctly decarbonise this sector of the economy.
- **Create a hydrogen industry in Portugal**: Hydrogen will be a key fuel for the decarbonisation of the Portuguese economy. A clear benefit from the conversion of gas networks to hydrogen is that it avoids the need for a disruptive conversion (i.e. the conversion of gas appliances to electric ones) both in industry and households, allowing for greater levels of social acceptance. Converting existing gas networks to hydrogen enables this fuel to be developed at scale.
- **Work towards supporting CCS where required**: Although the potential for CCS deployment is limited in Portugal, where both industrial heat and

process emissions need to be addressed the creation of CCS clusters is the most economical solution for their decarbonisation.

TABLE OF FIGURES

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Making Future

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