UK Energy Independence

Mapping out potential pathways to a more energy independent UK

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Research Report

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Introduction

The war in Ukraine has seen concerns about energy security in Europe, which the International Energy Agency (IEA) defines as an uninterrupted availability of energy sources at an affordable price, catapulted back to the top of the political agenda. This stems from the impact the conflict has had on the supply of fossil fuels to Europe, particularly for natural gas due to a number of countries having substantial dependence on Russian pipeline imports. In turn, these supply shocks have created significant turmoil in the continent's fossil fuel markets and sent prices rising, even for those countries with a comparatively small reliance on Russian oil and gas like the UK.

As with most developed countries, the UK has a high dependence on fossil fuels right across its economy and so the affordability challenges brought about by the current fossil fuel price crisis has ramifications for all sectors, from the oil used in transport to the gas used to heat more than 80% of the country's homes. Current estimates suggest that households in fuel poverty have increased by around 50% due to the crisis, rising to 6.7 million. With energy prices also feeding inflation, the increased costs of a wider set of consumer products have also impacted households.[1]

Recognising the importance of energy security and the country's exposure to the whims of global fossil fuel markets, the UK government has set out its response in the British Energy Security Strategy[2] (BESS) and the Energy Security Bill, which is intended to deliver key aspects of the BESS. The overall objective is to move the UK toward energy independence[3] by reducing its import dependency and relying more on domestic energy sources which, according to the BESS, include renewables, nuclear, hydrogen and oil and gas from the North Sea. The government has also begun to recognise the key role that energy efficiency must play in enabling greater energy security and have recently set a goal to reduce energy demand by 15% by 2030. After all, the most secure energy is the energy that is not required in the first instance.

However, the BESS neglects the critical issue that oil and gas produced in the UK is not owned by the Government but by private fossil fuel companies, and therefore will not be sold to the UK at a discount. This is a fundamental feature of oil and natural gas markets; they are global or regional and, as such, the price of these fuels are subject to factors beyond the UK's control. At best, North Sea production may contribute to the reliability of oil and gas supply but will not help tackle rising prices; these commodities will flow to whoever is willing to pay the most on the market, meaning that domestic prices will not benefit from increased domestic production.

Therefore, a genuinely energy independent future for the UK is one where the fossil fuel dependence of the whole energy system is reduced and, where possible, eliminated. This will also be critical for ensuring that the country's net-zero climate targets are met. The aim of this report is to explore potential UK energy futures with progressively greater ambition to phase out oil and gas across the economy. A more rapid reduction in oil and gas demand primarily supports the UK's energy independence by driving an earlier complete phase out of these fuels where possible, thereby insulating the country from the volatility of global fossil fuel markets. It also acts to bring demand in line with domestic production at an earlier date, thereby minimising dependence on imported fossil fuels, which is particularly relevant for natural gas. Combined this would mean a more affordable and reliable supply of energy to the UK. Greater ambition to phase out oil and gas would also have the benefit of being aligned with the country's goal to reach net-zero greenhouse gas emissions by 2050. This synergy between energy security and decarbonisation enables the conventional energy trilemma, i.e. the framing that the sustainability, reliability and affordability of energy must be traded off against one another, to be turned on its head.

This report is arranged as follows: in the next section we map out where oil and gas is used in the UK energy system and describe a set of levers to reduce their consumption. Following that we describe our scenario modelling approach, before analysing our scenario results and outlining a number of insights from this work.

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[1] https://www.nea.org.uk/energy-crisis/

[2] https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

[3] https://www.gov.uk/government/news/uk-government-takes-major-steps-forward-to-secure-britains-energy-independence

The Levers of UK Energy Independence

As described previously, the UK is currently heavily dependent on oil and gas, drawing on them to meet ~70% of its primary energy needs. In Figure 1Figure 1. we map out where oil and gas were being consumed across the UK's energy system in 2019 according the Digest of UK Energy Statistics (DUKES). This includes oil and gas being consumed for power generation and in end-use sectors, such as households and transport.

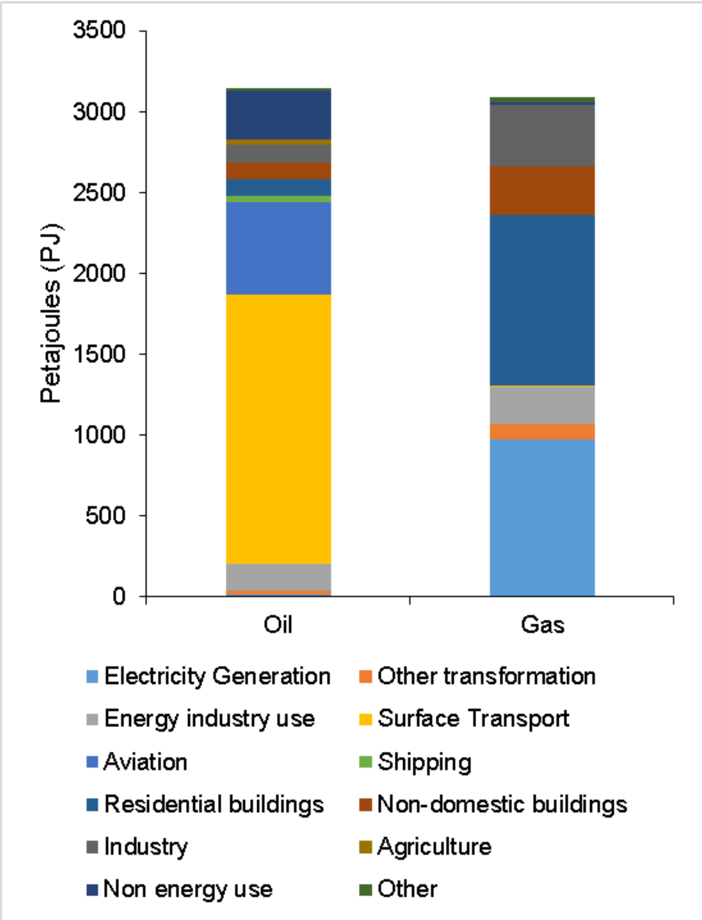

Figure 1. Oil and natural gas demand in the UK energy system by sector in 2019.

Figure 1 highlights that oil, in the form of petroleum products, is predominantly consumed by road and air transport and non-energy use, i.e. as a feedstock into the petrochemical industry, with smaller amounts used in shipping, buildings, industry and agriculture. Natural gas demand on the other hand comes from buildings, used mainly for heating from gas boilers, electricity generation and industry. This mapping exercise allows us to identify one or more "levers" that could be pulled for each sector to drive a reduction in the consumption of these fossil fuels. See Table 1 for a breakdown of the levers by sector.

Table 1. Scenario levers impacting the oil and gas consumption of the UK energy system

Sector	Lever
Residential	Heat pump roll-out rate in 2028
	Peak heat pump roll-out rate
	Year peak heat pump deployment achieved
	Residential energy demand, including space and water heat demand.

Transport	Date by which all new cars, vans, two wheelers and buses are zero emission.
	Date by which all new heavy goods vehicles are zero emission
	Share of sustainable aviation fuels (biofuels and synthetic kerosene) in 2050.
	Share of low carbon fuels (ammonia) in shipping in 2050.
	Transport energy demand across all modes
Electricity	Net-zero emission electricity
Non-domestic buildings	Share of low carbon fuels (electricity, hydrogen and biomass)
	Energy demand from non-domestic buildings
Industry	Share of low carbon fuels (electricity, hydrogen and biomass)
	Industrial energy demand including low and high temperature heat.
Carbon capture and storage (CCS)	Year in which CCS, including negative emission technologies like bioenergy with CCS and direct air capture, becomes available.
Hydrogen production	Share of low carbon (electricity and biomass) hydrogen production

These levers are not intended to cover all aspects of oil and gas demand but rather to identify the potential of targeting the largest consuming sectors first, to boost the transition to a more energy independent UK. Importantly, as supported by recent work which has highlighted the benefits of energy demand reduction[4], the levers include both the energy service demands in each end-use sector, e.g. useful heat demand in buildings or mobility demand for car travel; and the technologies needed to meet that demand, e.g. heat pumps or zero emission vehicles. They are also designed to connect with existing UK government policy where possible, such as heat pump roll-out rate in 2028. In so doing, they demonstrate what different levels of ambition could mean for the transition away from fossil fuels in each sector.

Two further aspects of future low carbon energy systems are also included in our levers. Firstly, we recognise the role that carbon capture and storage could play in oil and gas demand going forward, i.e. either by lowering the emissions of using these fuels or offsetting them altogether. A specific lever has been developed on CCS availability. This also captures the sizable uncertainty around if and when these technologies will appear at scale and that their earlier adoption could in fact prolong the UK dependence on fossil fuels, thus potentially exacerbating its exposure to global markets.

Secondly, today most hydrogen in the UK is produced from natural gas and used as a feedstock for the chemical industry. However, hydrogen is expected to be an important vector for decarbonising sectors which are hard to electrify. At the same time there remains substantial uncertainty around the relative mix of hydrogen production options that will be deployed, whether that be continued natural gas use with the addition of CCS, biomass with CCS or electrolysis coupled to low cost renewables. If it happens to be the former, this will lock in some level of continued dependence on natural gas within future low carbon energy systems, hampering efforts to move toward energy independence. Therefore, we develop a lever to explore this tension.

[4] Barrett, J., et al (2022). Energy demand reduction options for meeting national zero-emission targets in the United Kingdom. *Nature Energy*

Scenario Modelling Approach

The Scenarios

In this section we develop a set of scenarios which describe potential futures for the evolution of UK energy system from today to 2050 with progressively faster rates of oil and gas phase out, thereby mapping out possible routes to a more energy secure system. To do this, we quantitatively elaborate the lever framework detailed previously across a series of progressively more ambitious levels for each lever. Table 2 details the three scenarios which are the result of this process, namely *Emerging*, *Developing* and *Secure*.

Table 2. Scenario lever assumptions

		Scenario		
Sector	**Lever**	***Emerging***	***Developing***	***Secure***
Residential	Heat pump roll-out in 2028	600,000 per year	900,000 per year	1.1m per year
	Peak heat pump roll-out	1m per year	1.5m per year	2m per year
	Year peak heat pump roll-out achieved	2037	2035	2033
	Residential energy demand	LED Steer[a]	LED Shift [a]	LED Transform [a]
Transport	All new cars, vans, two wheelers and buses are zero emission.	2035	2030	2025
	All new heavy goods vehicles are zero emission	2040	2035	2030
	Share of sustainable aviation fuels in 2050	10%	50%	95%
	Share of low carbon fuels in shipping in 2050	25%	50%	95%
	Transport energy demand across all modes	LED Steer	LED Shift	LED Transform
Electricity	Net-zero emission electricity	2035	2032	2030
Non-domestic buildings	Share of low carbon fuels	60%	70%	80%
	Energy demand from non-domestic buildings	LED Steer	LED Shift	LED Transform
Industry	Share of low carbon fuels	60%	70%	80%
	Industrial energy demand	LED Steer	LED Shift	LED Transform
CCS	Year from which CCS is available	2030	2035	2040
Hydrogen production	Share of low carbon hydrogen production 2030 to 2050	50% (2030) 50% (2050)	50% (2030) 90% (2050)	80% (2030) 100% (2050)
	[a] https://low-energy.creds.ac.uk/the-report/			

The energy service demand projections in each sector are sourced from the Centre for Research into Energy Demand Solutions (CREDS) Low Energy Demand (LED) report[5]. That study's Shift and Transform pathways set out futures that see progressively more effort given to reduce energy demand relative to its Steer baseline projection. This growing ambition spans behavioural aspects, like modal shift in transport, as well as more technical factors, like insulation in residential buildings (see the Annex of this report for a set of graphical examples of the energy service demand trajectories we use and the CREDS LED report for further details). We also draw on, where relevant, the detailed end-use sector expertise from the LED study when informing some of our lever levels, e.g. the phase out dates for the sale of new internal combustion engine (ICE) cars and vans.

A key challenge in setting these levels is ensuring they span a range that is both feasible and ambitious, thereby grounding our scenarios in the possible. To inform this we draw on a number of sources including UK government targets, the academic literature, and our existing academic network as well as existing energy scenarios from the Climate Change Committee (CCC) and the National Grid (NG). Taken together, these serve as a benchmark to shape our selections.

Our reference scenario, *Emerging*, draws heavily on current UK government policy where possible, for instance matching the current targets of 600,000 heat pump installations per year by 2028 and the phase out of the sale of new ICE cars and vans by 2035. The *Developing* scenario then goes on to push these levels somewhat higher and more in line with the CCC's Balanced Net-zero Pathway, a roughly middle of the pack position when compared to the scenarios from CCC and NG. Finally, our *Secure* scenario stretches further still with typical ambition that is slightly beyond, but only just, the more ambitious cases from existing scenario exercises in most areas.

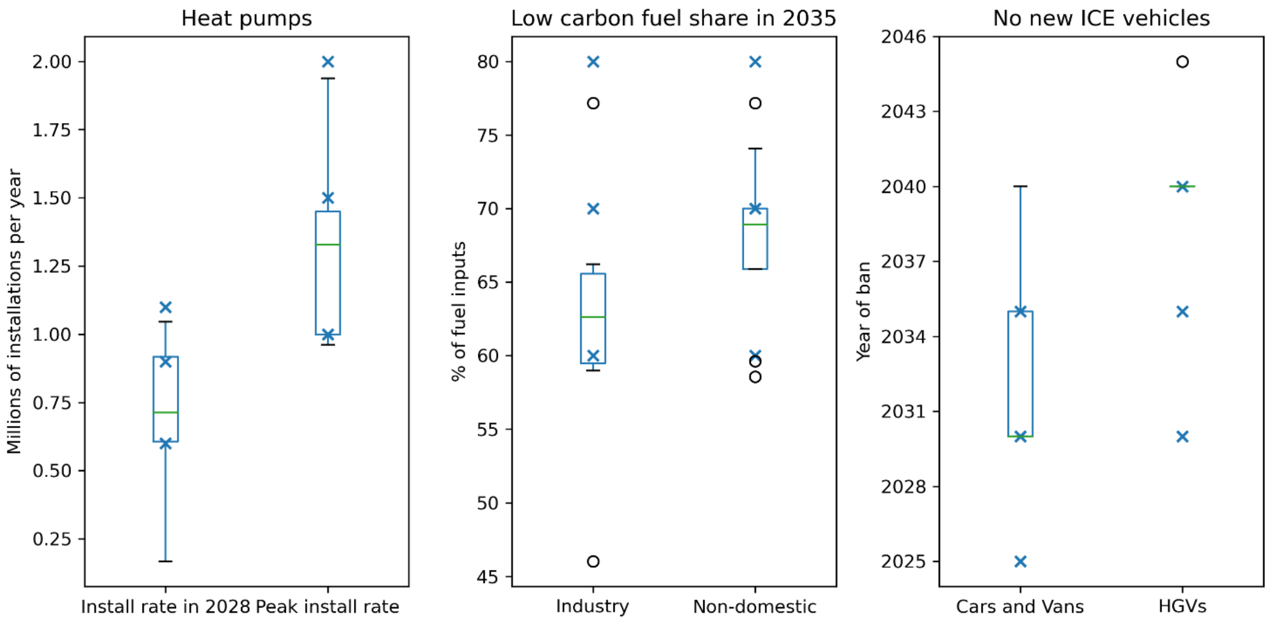

Figure 2. Selected lever assumptions from this work (blue crosses) compared with assumptions made in scenarios from the CCC Sixth Carbon Budget report and NG Future Energy Scenarios 2022 (box plots, n=9). Outliers from the boxplots are shown as white circles, e.g NG Falling Short scenario only phasing out new ICE HGVs in 2045.

To place our scenarios in context across various design decisions, in Figure 2 we compare our three scenarios with the five from the CCC's Sixth Carbon Budget report[6] and the four featured in NG Future Energy Scenarios 2022 report[7]. Here we see that for the levers compared, our first two scenarios generally span the range defined by these cases from the literature. *Secure* then pushes to be, in the main, marginally more ambitious than the futures space explored thus far.

It is also worth putting our levers in context with the ongoing transition in other European countries. For space heating, the EU's REPowerEU policy package, which is a direct response to the fossil fuel price crisis driven by the

[5] https://low-energy.creds.ac.uk/the-report/
[6] https://www.theccc.org.uk/publication/sixth-carbon-budget/
[7] https://www.nationalgrideso.com/future-energy/future-energy-scenarios

war in Ukraine, has seen a 38% increase in heat pump installation from 2021 to 2022[8]. Italy leads the way with nearly 500,000 heat pumps sold in 2022 (following a 37% growth from 2021) with other populous countries like France and Germany seeing around 300,000 (up 30% from 2021) and 275,000 (up 58% from 2021) installations, respectively. The UK is lagging behind these other countries with around 60,000 heat pumps sold in 2022. Similar growth to that seen in the other nations could yet see the UK reaching or exceeding its 2028 Government target of 600,000 installations per year, provided the necessary policy support is forthcoming to sustain it. We note that it is yet to be seen whether the aforementioned countries will be able to maintain these deployment rates over many years, as is necessary to enable a more secure and low carbon energy system. Nevertheless it is instructive to note what is possible in similarly populous countries with focused policy.

Electric car penetration is another noteworthy comparator, with the European leader Norway seeing 79% of new car sales in 2022 being full battery electric[9] compared with the UK recording a 16.6% share. While the country contexts are different, for instance Norway is less populous with a higher GDP per capita, it is useful to observe that it has taken Norway around 7 years to increase the share of new cars which are battery electric from roughly today's UK level to its present figure.

Modelling with UK TIMES

To quantitatively describe our future UK energy scenarios, including the levers, we use the UK TIMES whole energy system model which uses the TIMES modelling framework, a modelling paradigm that is widely used to represent local, regional or national energy systems. It relies on a least-cost linear optimisation framing (based on minimising total discounted net present value) to assess and compare different future evolutions of the energy system it represents. It does not extend to include all aspects of the wider economic system, such as GDP or employment, and is therefore referred to as a partial equilibrium model.

The model has been widely used to inform UK energy scenario studies[10], and has been co-developed with UK government to support the publication of successive carbon budget analyses and national energy strategies[11]. As such, it sits at the heart of future energy pathway analyses for the UK, playing an essential integrating role by bringing detailed sectoral perspectives together into one internally consistent frame of reference.

UK TIMES provides a representation of the whole energy system for the UK, from the energy resources we produce or import, to the generation of electricity, and then energy use in the economy, transport systems and households. The model considers the existing system as of 2010, including existing infrastructure (e.g. the existing power system or current vehicle stock), and combines this with a selection of new technology options in order to build the energy systems required under different future pathways. The model is driven by future changes in energy demand needed to heat our homes, for industrial output, and to transport goods and people. Projections of these future demands are taken from the CREDS LED report as detailed previously.

The whole system nature of the model is key as it ensures that the future pathway analysis is internally consistent. Demands for energy commodities such as hydrogen or electricity are estimated based on the relative needs of different sectors and on the levels of final energy demands over time. In turn, these demands will determine the level of upstream resources that is required, including imports and domestic extraction, and the necessary investments in the power generation sector. The flows of these commodities between and across sectors is price

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[8] All data in this paragraph taken from https://www.carbonbrief.org/guest-post-how-the-energy-crisis-is-boosting-heat-pumps-in-europe/

[9] https://robbieandrew.github.io/EV/

[10] Pye, S., Li, F. G. N., Price, J. & Fais, B. Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era. *Nat. Energy* **2**, 17024 (2017).
Broad, Oliver, Graeme Hawker, and Paul E. Dodds. "Decarbonising the UK residential sector: The dependence of national abatement on flexible and local views of the future." *Energy Policy* 140 (2020)

[11] Impact assessment for the sixth carbon budget, https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf
HM Government. *Building our industrial strategy*. https://beisgovuk.citizenspace.com/strategy/industrial-strategy/supporting_documents/buildingourindustrialstrategygreenpaper.pdf (2017).
DECC. *Impact Assessment for the level of the fifth carbon budget*. http://www.legislation.gov.uk/ukia/2016/177/pdfs/ukia_20160177_en.pdf (2016).

sensitive and driven by the dynamics of balancing supply and demand across the entire system, including trading-off sectoral needs. Finally, this representation ensures the comprehensive accounting of both emissions and removals of energy-related GHG emissions for each future energy pathway. All scenarios modelled here are constrained to meet the UK's domestic carbon budgets and net-zero greenhouse gas emissions target by 2050.

Pathways to an Energy Independent UK

Total UK Oil and Natural gas Demand

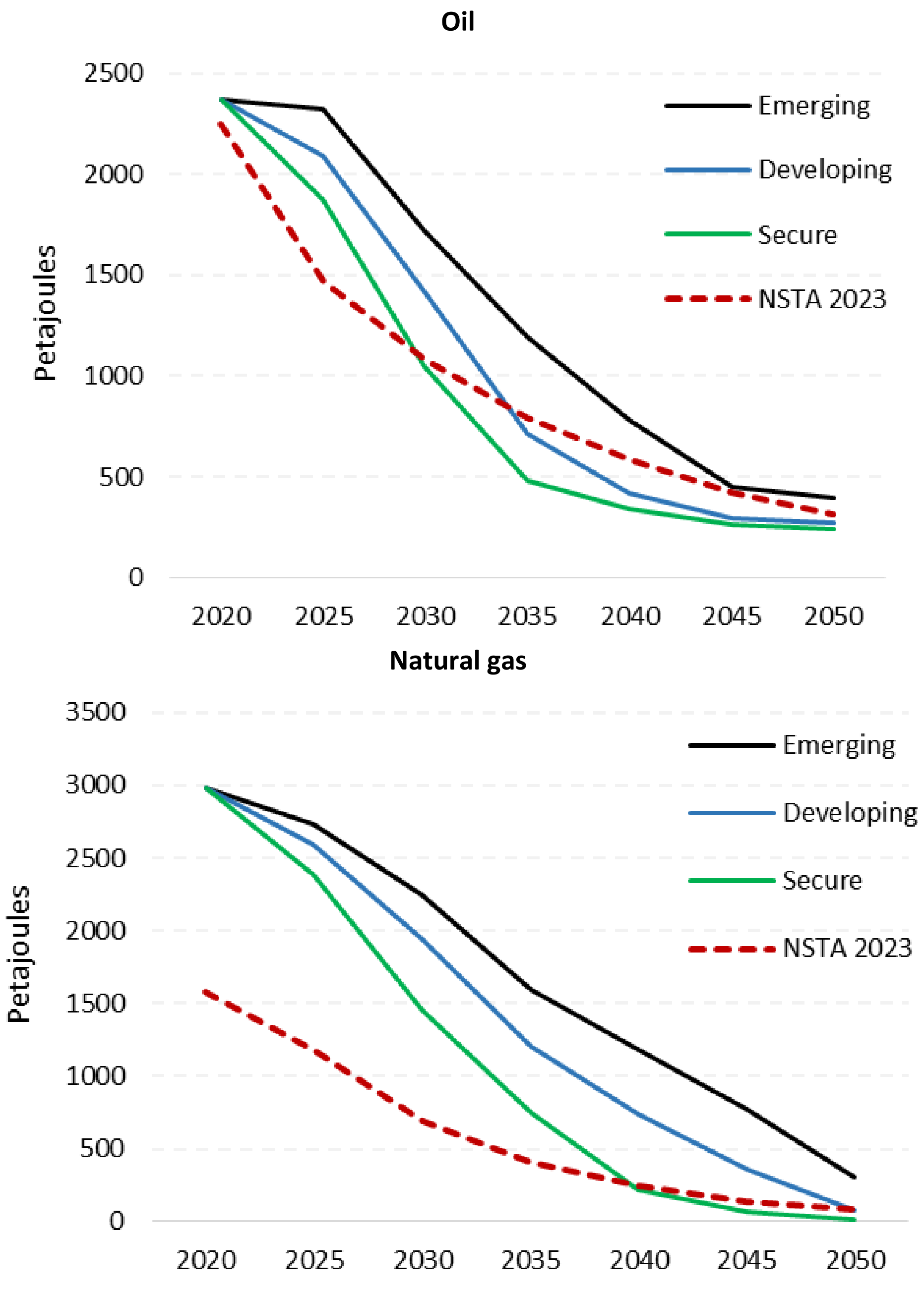


Figure 3. Oil (top panel) and natural gas (bottom panel) demand from the UK energy system in our scenarios compared with NSTA projections of production updated in February 2023

As discussed previously, a more energy independent and secure UK is one that minimises its exposure to global oil and gas markets going forward by phasing out the use of these fuels. In Figure 3 we show the oil and gas demand from the whole UK energy system, including non-energy use, across the three scenarios we model here. We also include UK oil and gas production projections from the North Sea Transition Authority (NTSA) as of Feb 2023 which allows us to assess the import dependency for each fuel, i.e. demand below production means no net imports.

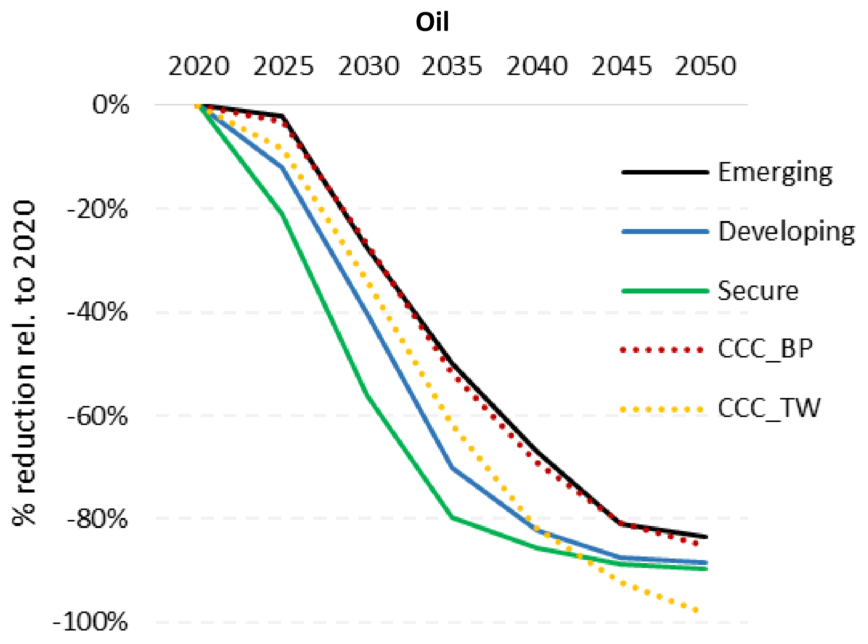
Starting with oil, we see a substantial reduction in its demand across all cases with, as expected, the rate of decline increasing markedly with increasing levels of scenario ambition, from *Emerging* to *Secure*. The three cases all tend toward a minimum level in oil demand set by non-energy use in the petrochemicals sector, particularly in *Developing* and *Secure* which nearly phase out all other oil demands. This floor is, in part, a reflection of UKTM not yet including options to substitute this non-energy consumption with alternative feedstocks. Nevertheless, we see that the UK could achieve a position such that it requires no net imports, a first step toward true energy independence, by 2030 under *Secure* and 2035 under *Developing*.

For natural gas, we again see a progressively faster reduction in demand to 2050 across the scenarios with *Developing* and *Secure* reaching essentially zero consumption by mid-century i.e. a complete phase out of the UK energy system's dependence on gas. Importantly, only the *Secure* scenario sees the UK reaching no net imports by 2040, i.e. the initial stage of energy independence. This implies that the goal of energy independence could be achieved by that year if the levers we explore here were to be fully pulled. *Developing* sees no net imports reached by 2050 while the demand in the *Emerging* case is still slightly too high to be met with North Sea production.

As set out in the introduction, achieving energy independence is not the only goal of removing fossil fuels from the UK energy system. A more rapid transition to a system much less dependent on oil and gas addresses multiple other challenges including affordability of energy supply, particularly given the quickly reducing costs of renewables and electrification via electric vehicles and heat pumps, job creation[12], and at the same time climate change. In this section, we have shown that an energy transition in which the levers set out in *Secure* were fully implemented could see the UK having no net import dependence from 2040 and, other than chemical feedstocks, having phased out fossil fuels almost entirely by 2045.

Comparison to the CCC Sixth Carbon Budget scenarios

Next, we compare the pathways produced by our modelling to those from the CCC Sixth Carbon Budget report, which was published in December 2020. The CCC pathways have long been used as a benchmark against which to assess future domestic production and import requirements. We present this comparison in terms of relative percentage changes normalised to 2020 to avoid various potential issues impacting our analysis, e.g. the impact of the COVID-19 pandemic not yet being fully realised while the CCC modelling was being conducted in 2019-20. We focus on two scenarios from the CCC, namely their central case, Balanced Net Zero Pathway (BP), and their most ambitious, Tailwinds (TW), which benefits both from more behaviour change and greater innovation.



[12] https://ukerc.ac.uk/publications/green-jobs/

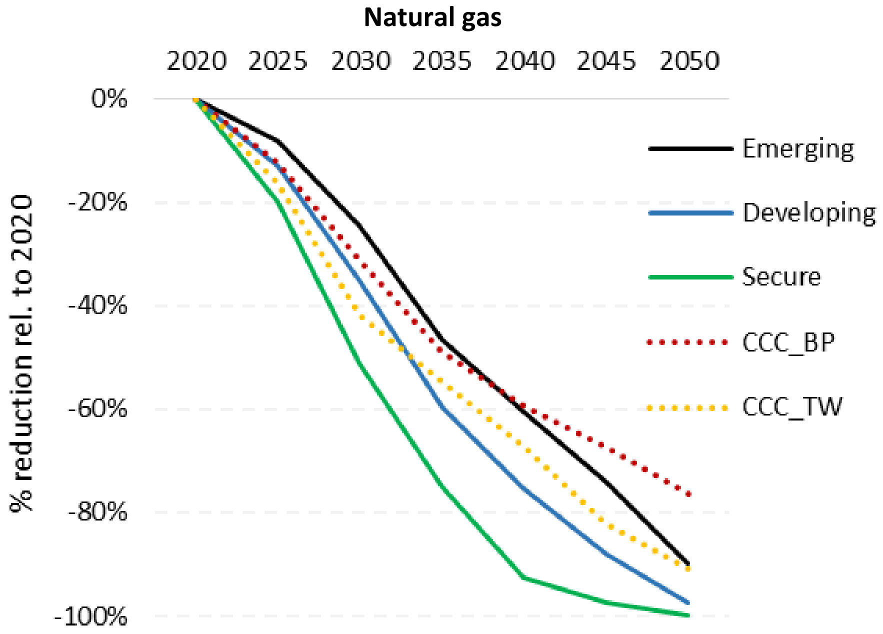


Figure 4. Change in oil (top panel) and natural gas (bottom panel) demand from the whole UK energy system in our scenarios compared with CCC Balanced Pathway (BP) and Tailwinds (TW).

In Figure 4 we compare total oil (top panel) and natural gas (bottom panel) demand pathways for the UK's energy system. Here we see that for oil and gas, at least until 2035, our *Emerging* and *Developing* scenarios are broadly in line with the CCC's BP and TW, respectively, while *Secure* offers notably greater ambition on demand reduction, particularly for natural gas post 2030. Based on the data available it is unclear whether the CCC scenarios include oil feedstock demand for petrochemicals, which may explain why TW is able to reach an almost 100% reduction by 2050. The differing levels of ambition demonstrated by this comparison points to why our scenarios are able to reach no net oil and gas imports whereas the central CCC case, BP, does not (see Ref[13]).

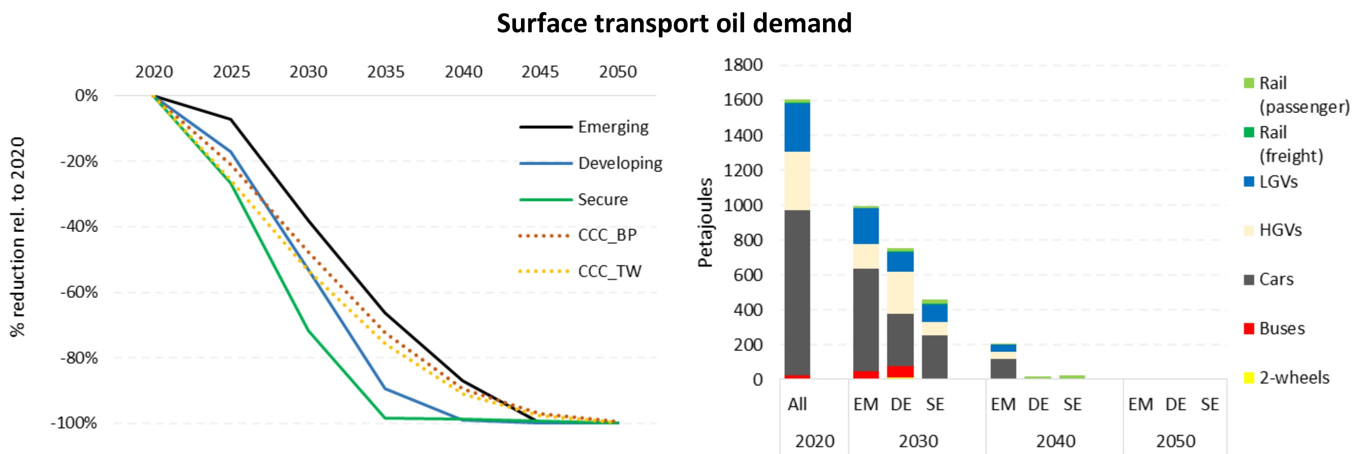


Figure 5. Change in oil demand in surface transport in our scenarios compared with CCC BP and TW (left panel) and sub-sector oil demands across our scenarios (right panel). Here Emerging is EM, Developing is DE and Secure is SE.

Next, we move to a selection of sector-based comparisons, beginning with surface transport shown in Figure 5, which accounted for over 81% of oil consumption in transport in 2020. It shows a comparison to the CCC scenarios in the left panel while in the right panel, the demand trajectory is split into sub-sectors. Taken together, these plots highlight the growing ambition within our scenarios which see an effective end to oil use in this sector by 2045, 2040 and 2035 in *Emerging*, *Developing* and *Secure*, respectively. This is driven by a combination of earlier ICE phase out dates and lower mobility demands as one moves through the scenarios (the relative balance of these factors will be

[13] https://www.theccc.org.uk/publication/letter-climate-compatibility-of-new-oil-and-gas-fields/

explored later in this section). Here we see that *Developing* and *Secure* are more ambitious than the CCC cases from 2030 and 2025, respectively.

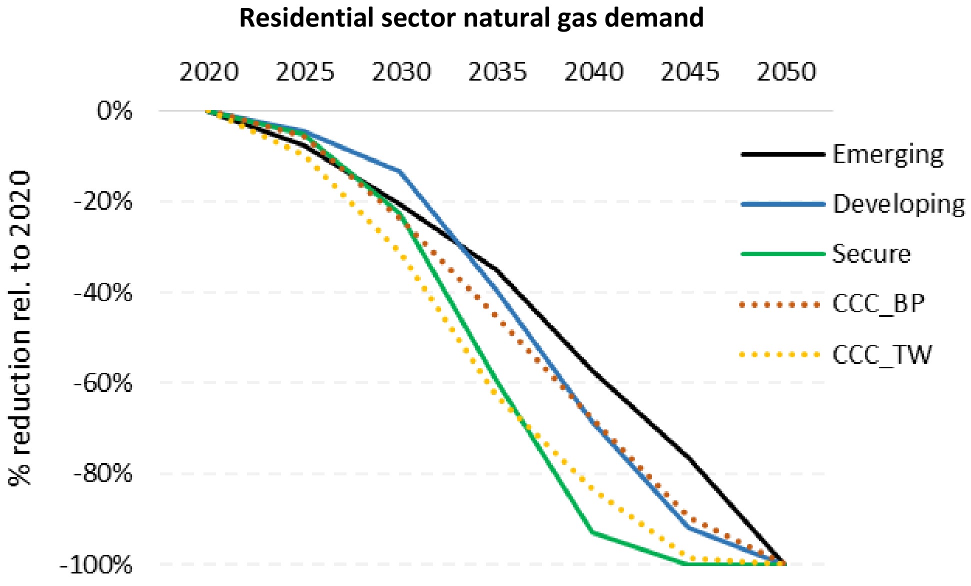


Figure 6. Change in residential natural gas demand from our scenarios compared with CCC BP and TW

In terms of natural gas demand, the most important sector in the UK energy system today is residential, accounting for more than 40% of consumption and the majority of that in space and water heating. In Figure 6 we demonstrate that our *Developing* and *Secure* scenarios are broadly similar to BP and TW, respectively, with the CCC cases generally showing more rapid reductions to the 2030s before being caught up with or overtaken. The *Secure* scenario sees a 93% reduction in natural gas demand by 2040 and a complete phase out from the UK's homes by 2045, which goes a significant distance towards enabling the requirement for no net imports of natural gas from 2040 that was shown previously under this scenario (see Figure 3). It is clear that a rapid removal of natural gas from the UK's residential sector, operationalised by an ambitious deployment of heat pumps and efforts to reduce heating requirements through retrofitting, is critical to achieving energy independence.

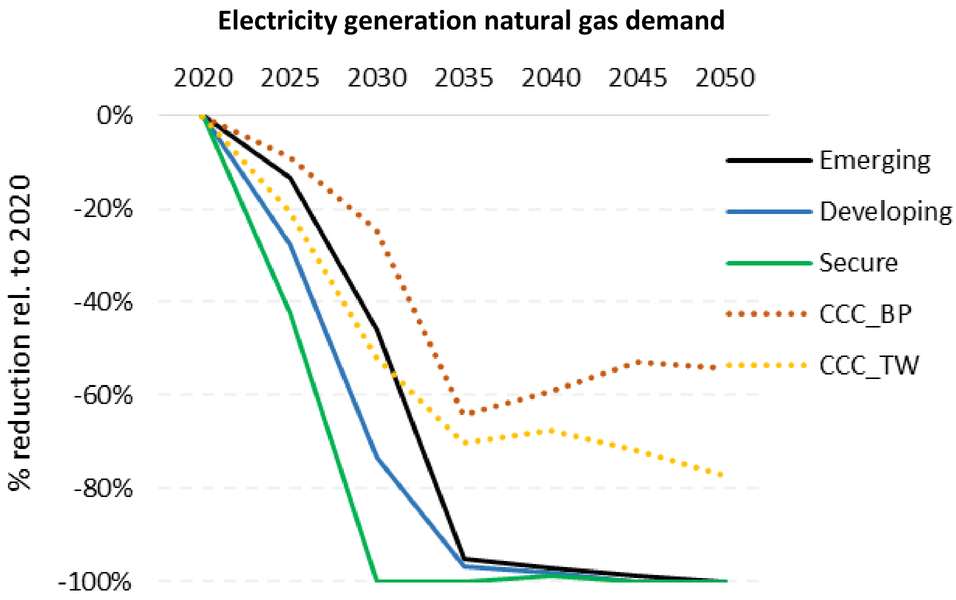


Figure 7. Change in natural gas demand from electricity generation in our scenarios compared with CCC BP and TW.

Electricity generation is another key sector for natural gas consumption today but one that is set to change rapidly in the coming decade as the UK moves to meet the Government's target of a net-zero emissions power system by 2035 and delivers an extensive build-out of offshore wind by 2030. In Figure 7 we see that out scenarios are generally more ambitious than their CCC counterparts. The vast majority of gas consumption is phased out by 2035 (*Emerging* and *Developing* have 30-40 PJ by this date), while CCC BP/TW still have 200-300 PJ of gas consumption in the 2030s. However, the CCC has recently updated this and now expects ~150 PJ of gas demand for power in 2035 which falls to ~ 82 PJ in 2050[14]. Our modelling here does include a mixture of back up plants (fuelled by hydrogen) and storage to provide system adequacy. Previous research with a high resolution electricity model has shown that net-zero power systems with no or very close to zero natural gas demand (<10 PJ) are feasible and cost-effective when supported by low carbon hydrogen production and long-term storage[15].

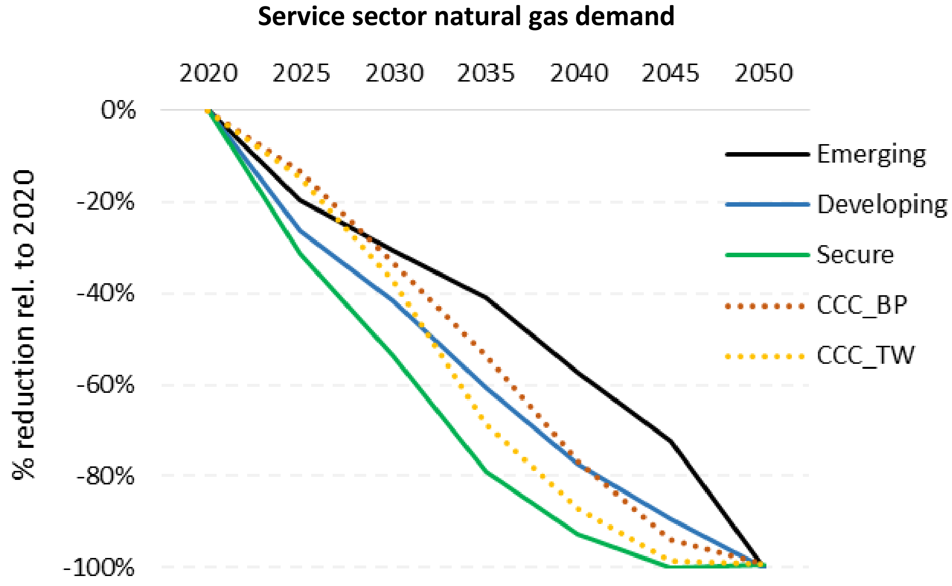


Figure 8. Change in natural gas demand from the service sector in our scenarios compared with CCC BP and TW.

Natural gas demand in the service sector, used primarily for space and water heating in both public and commercial buildings, is compared in Figure 8. Here we again see a pattern such that *Developing* is comparable, at least from 2030, to the CCC scenarios while *Emerging* falls behind during this decade. *Secure*, once more, shows a greater rate of demand decline with the sector being essentially natural gas free (~93% reduction) from 2040, ahead of the other four scenarios which reach this position in 2045 or 2050.

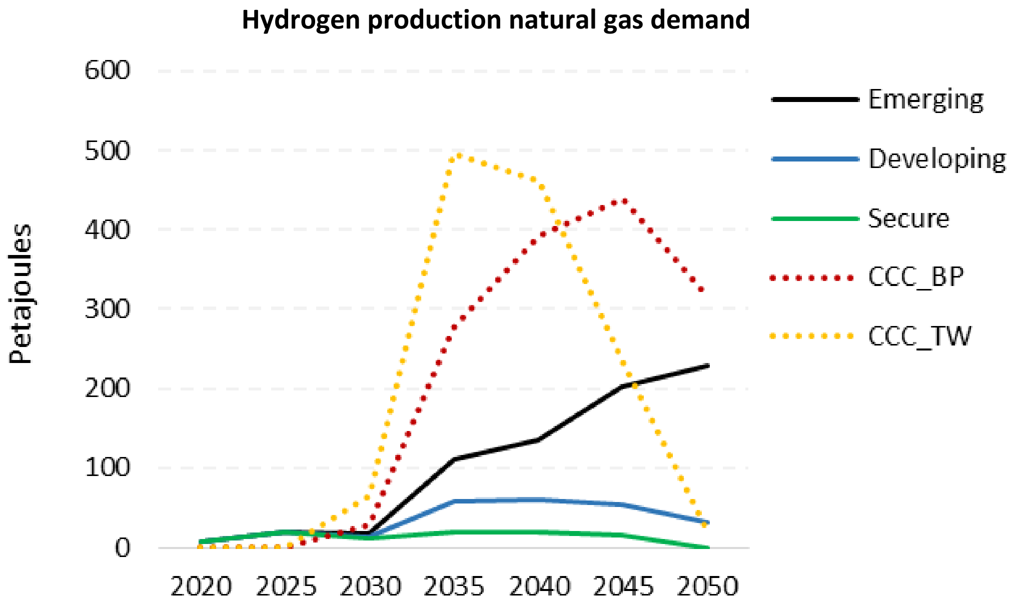


Figure 9. Absolute natural gas demand for hydrogen production for fuel in our scenarios compared with CCC BP and TW.

[14] https://www.theccc.org.uk/publication/delivering-a-reliable-decarbonised-power-system/

[15] Price, J., Keppo, I., & Dodds, P. E. (2023). The role of new nuclear power in the UK's net-zero emissions energy system. *Energy*

Finally, in Figure 9 we compare changes in natural gas demand for hydrogen production for use as a fuel with those from the CCC scenarios, in absolute units. While this is a new sector, i.e. only minimal amounts of hydrogen are currently used for energy applications, it is expected to grow substantially as the UK decarbonises. Significant uncertainty however remains as to how it will be produced. Our scenarios describe a range of pathways, varying from a significant role for natural gas in *Emerging*, to close to no role at all in *Secure*, which produces hydrogen entirely from electrolysis and bioenergy with CCS by 2050. Interestingly, we see that the CCC envisages much larger demands for natural gas per year (equivalent to 15-17% of the total amount of natural gas consumed by the UK in 2020), which in BP is mostly sustained until 2050. Indeed, around 50% of natural gas demand in TW in the mid-2030s to early 2040s is coming from hydrogen production (coupled to CCS, i.e. so-called blue hydrogen). We argue it may be unwise to develop such a sizable natural gas demand for hydrogen production during this period for a number of reasons including: i) concerns around energy security and the push for energy independence, ii) uncertainty regarding just how cheap renewables and, particularly, electrolysers (as acknowledged by the Government[16]) are likely to be become and iii) due to the need for strong regulation to ensure blue hydrogen is indeed low carbon and the risk that this does not materialise[17].

In summary, we find that the *Emerging* and *Developing* scenarios developed in this work are broadly similar in their oil and gas phase out trajectories to CCC BP and TW. Our *Secure* scenario then offers a further step up in ambition toward achieving the goal of UK energy independence. For oil, this is enabled by a faster phase out of from the transport sector. For natural gas, the greater ambition is driven by a combination of faster declines in sectors such as residential, services and power and, crucially, a hydrogen production sector that does not rely substantially on natural gas.

Decomposition of the Scenarios

In this section we identify the contribution from each sector to the phase out of oil and gas across our scenarios. In Figure 10, we show the picture for oil which, as mentioned previously, is dominated by changes in transport demand. The panels compare our *Emerging* scenario with *Developing* (left) and *Secure* (right) and clearly show that the lower oil demand in the latter is driven through greater ambition across its transport levers with only a small contribution from other sectors, which here is a combination of buildings, industry, power, non-energy, upstream, agriculture and hydrogen.

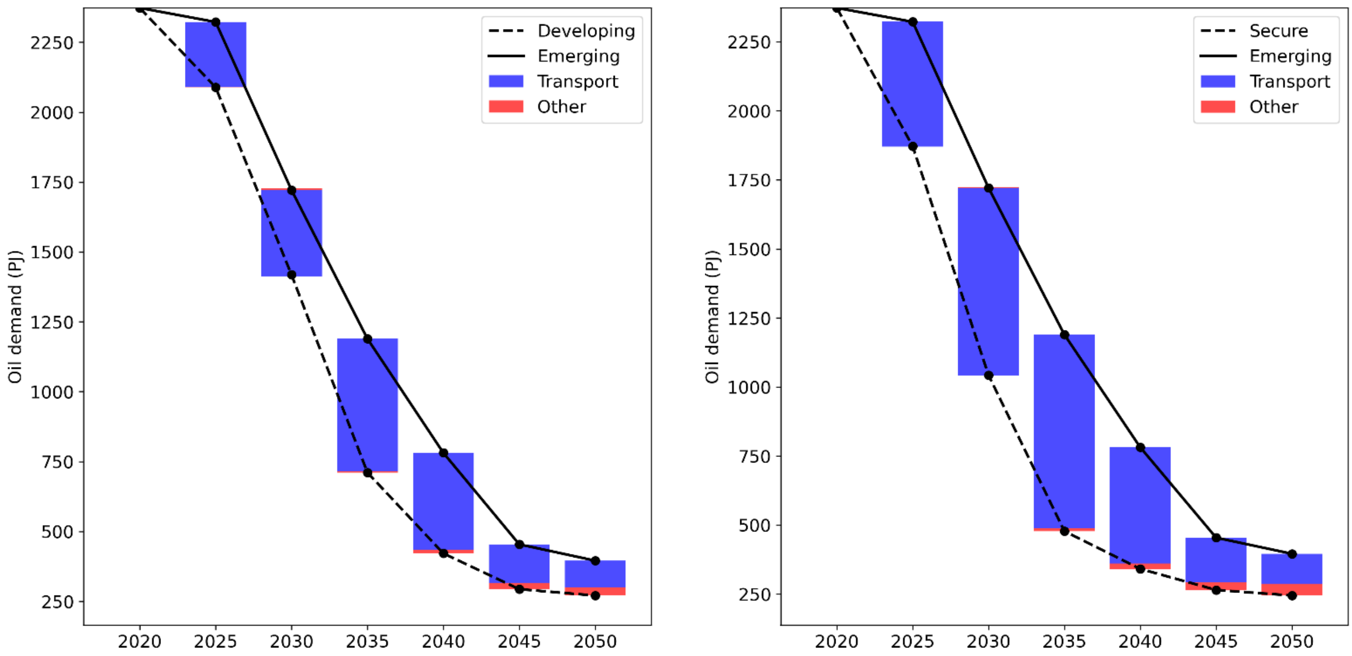


Figure 10. Change in oil demand between Emerging and Developing (left panel) and Secure (right panel) by sector. Other includes buildings, industry, power, non-energy, upstream, agriculture and hydrogen. Boxes show the sectoral change relative to Emerging which in some cases can be positive, thus the boxes can extend above and below the trajectory of each scenario.

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[16] https://www.gov.uk/government/publications/hydrogen-production-costs-2021

[17] Bauer, C. et al. (2022). On the climate impacts of blue hydrogen production. *Sustainable Energy & Fuels*

Next, in Figure 11 we show the sectoral contribution to reductions in natural gas demand by scenario and, predictably, see a much more mixed picture than for oil. From these plots, it is clear that reductions in demand from the electricity system, and to a lesser extent industry, shape the near-term (to 2030) differences between the scenarios. Falls in natural gas demand in buildings then begin to dominate, particularly in *Secure*, from 2035 with differences driven by hydrogen production featuring from 2040 onwards. Indeed, natural gas for hydrogen makes up essentially all the difference between scenarios in 2050.

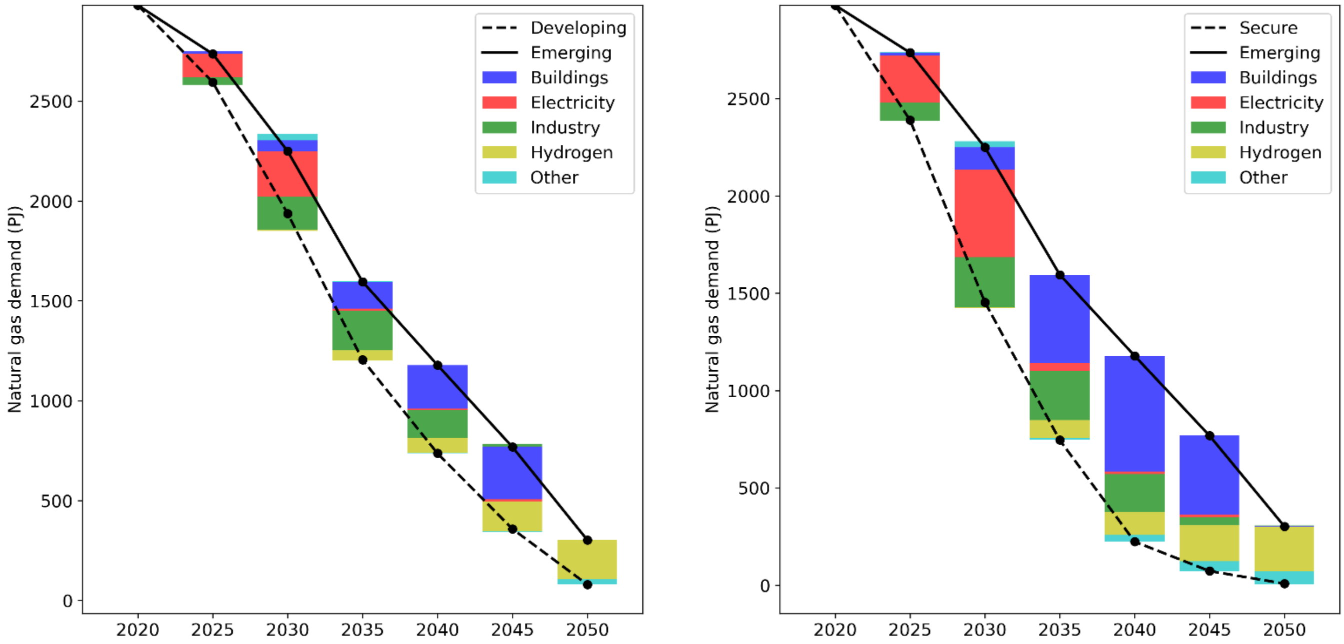

Figure 11. Change in natural gas demand between Emerging and Developing (left panel) and Secure (right panel) by sector. Other includes non-energy, upstream, agriculture and transport. Boxes show the sectoral change relative to Emerging which in some cases can be positive, thus the boxes can extend above and below the trajectory of each scenario.

Insights and conclusions

In this report we have sought to explore UK energy futures which are progressively more energy independent by ratcheting up policy ambition to phase out oil and gas demand, thereby limiting the country's exposure to volatile global fossil fuel markets. The result of this are visions of a potential future UK energy system that offers a more reliable and affordable supply of energy. From this exercise we have found:

- In an energy transition in which the levers set out in *Developing* and *Secure* were implemented in full, the UK could achieve a near total phase out of oil demand by 2045 in the former and 2040 in the latter. The majority of remaining demand would be for non-energy uses, i.e. petrochemical production. Furthermore, our scenarios also describe a future where the UK's oil import dependence rapidly reduces with no net imports from 2035 in *Developing* and 2030 in *Secure*.
- In a similar vein for UK natural gas demand, the levers we explore could also realise a near complete phase out of demand by 2050 in *Developing* and 2045 in *Secure*, implying that insulation from volatile global natural gas markets could be reached by these dates. Indeed, we found that no net import dependence for natural gas can be reached by 2050 in *Developing* and as early as 2040 in *Secure*.
- Our modelling shows that a full implementation of the levers set out in *Secure*, enabled by a step change in energy policy commensurate with a drive for genuine energy security, could see the UK having phased out fossil fuel consumption almost entirely by 2045, aside from chemical feedstocks, and have no net import dependence from 2040.
- We have found that our *Emerging* and *Developing* scenarios have broadly similar oil and gas phase out trajectories to that depicted in the CCC's BP and TW scenarios with our *Secure* scenario then offering greater ambition and, as such, more rapid progress toward UK energy independence.
- We argue that the UK developing a substantial natural gas demand for hydrogen production, as set out by the CCC's BP and TW scenarios from 2030 onwards, would be incompatible with the country's energy

independence objectives and could carry increased risk from techno-economic and climate perspectives. It is also unclear whether businesses and investors would be encouraged to support an industry that, according to CCC TW scenario, could have only a 20-year lifespan (2030-2050) at best.

Here we have mapped out the route to a rapid energy transition which sees the UK prioritising energy security by quickly weaning itself off its dependence on oil and gas, and the global markets they are coupled to. In so doing, such a transition would also address a number of other challenges facing the UK today including the affordability of energy, responding to climate change and job creation. Taken together, this represents an unprecedented opportunity to reverse the conventional narrative that energy security, affordability and sustainability must be traded off against one another by instead realising they are in fact synergistic in the context of a transition away from fossil fuels.

Annex

Biomass demand

Biomass may play an important role in decarbonising parts of the UK energy system and potentially enabling negative emissions through bioenergy with carbon capture and storage (BECCS). However, its use is controversial because of questions around its sustainability both environmentally and from a broader socio-economic context, e.g. food vs fuel. Concerns have also been raised around social equity and justice relating to the establishment of international supply chains for biomass commodities. In our scenarios we have assumed a supply limit of ~ 560 PJ in 2050 which is taken from scenario 2 of the CCC's Biomass report from 2018[18]. In Figure 12, we compare the 2050 biomass demand from our scenarios to those from the CCC Sixth Carbon Budget.

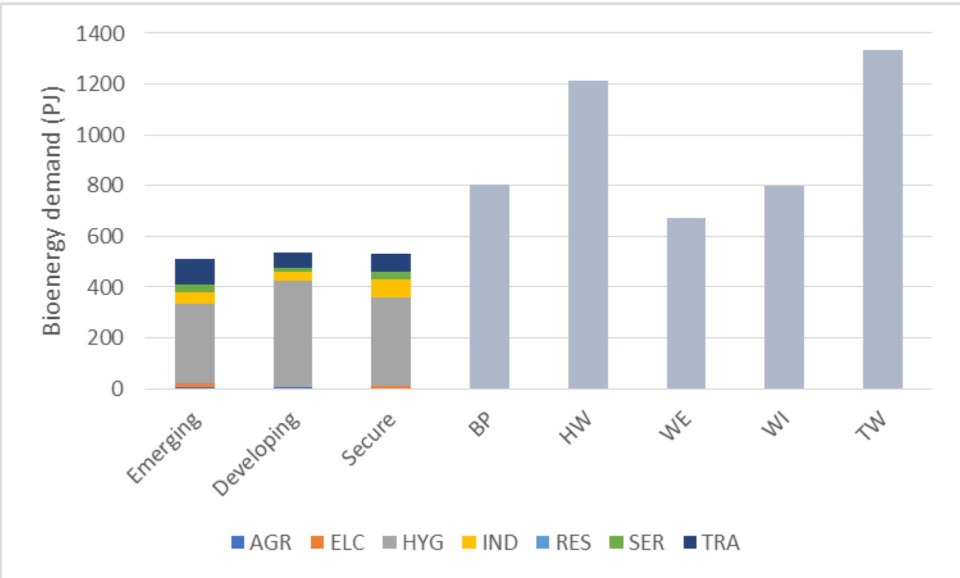

Figure 12. Biomass use in 2050 across our three scenarios by sector compared with total biomass use in the five scenarios from the CCC's Sixth Carbon Budget report. AGR is agriculture, ELC is electricity, HYG in hydrogen production, IND is industry, RES is residential, SER is services and TRA is transport.

We see that our scenarios use between ~508-535 PJ of biomass in 2050, very close to the assumed supply limit built into our modelling. DUKES assessed UK renewable biomass consumption to be ~ 509 PJ in 2020, therefore we envisage an approximate continuation of the demand level seen today, albeit with some sources diminishing (e.g.

[18] https://www.theccc.org.uk/wp-content/uploads/2018/11/Biomass-in-a-low-carbon-economy-CCC-2018.pdf

landfill methane) and others growing (e.g. wood pellets). The majority of biomass demand in 2050 in our scenarios is for hydrogen production followed by transport, industry and the service sector.

Figure 12 highlights that our scenarios use considerably less biomass in 2050 than the CCC cases, which vary between ~ 670-1330 PJ (excluding fossil based municipal solid waste). The upper limit of that range is particularly striking, with TW assuming a near tripling of biomass demand by mid-century.

Energy service demands

In this section we provide a selection of examples of the energy services used in this work which, as detailed previously, are all taken from the CREDS Low Energy Demand report. In Figure 13 we show four of the eleven different modes of transport demand represented in UKTM. Generally speaking, there is a trend of less demand as one moves from *Emerging* to *Secure*, although bus demand moves in the opposite direction due to the shift from private to public transport. The rapid drop in international aviation in 2020 is due to the Covid pandemic with the three scenarios then envisaging different recovery trajectories for the sector.

Figure 13. A selection of energy service demands from the transport sector in UKTM by scenario. Trajectories show relative change in demand from 2010.

Figure 14 shows key, i.e. those that dominate each sector, energy service demands from residential, services and industry, where the latter is an aggregation across the whole sector. Once more there is a general trend such that higher demands are seen in *Emerging* compared to *Secure*.

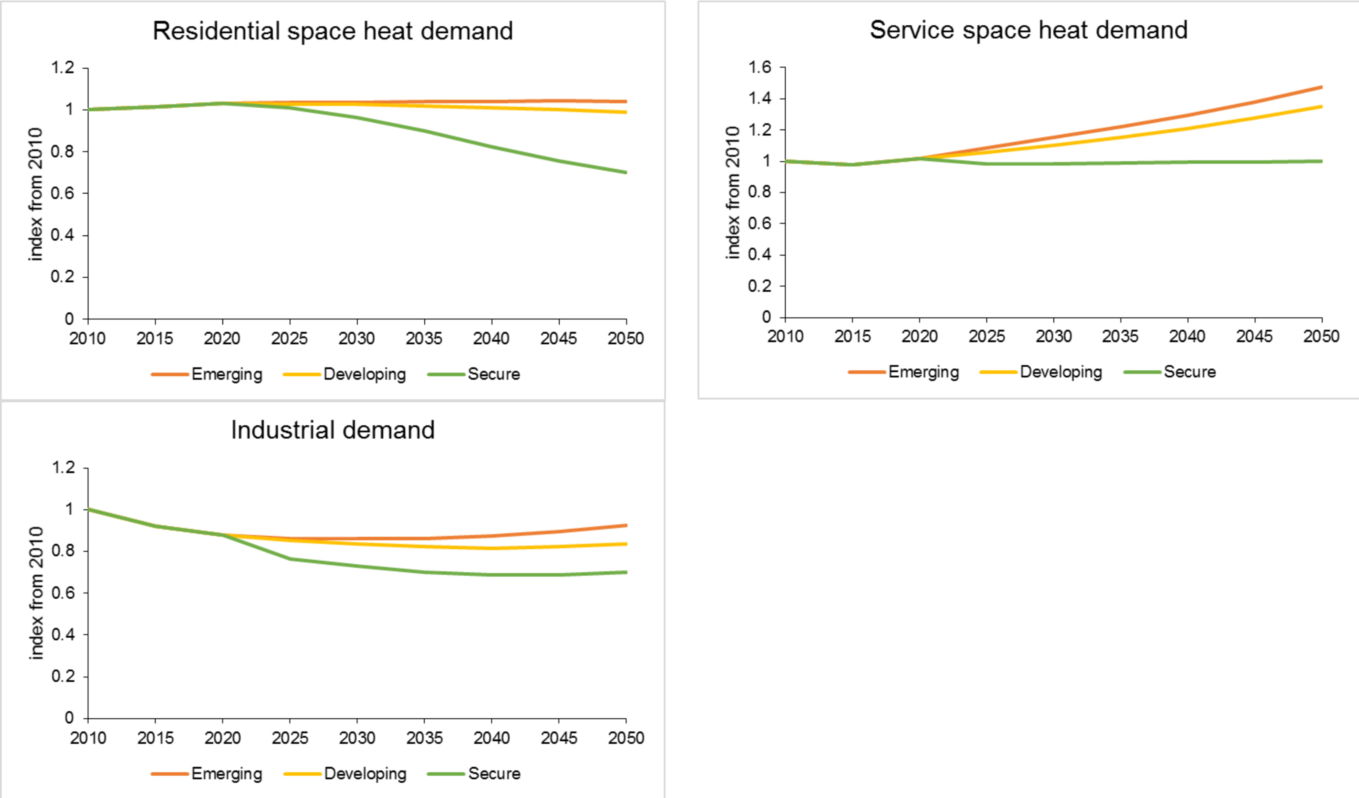

Figure 14. Key energy service demands across the residential, service and industrial sectors. Pathways are relative change in demand from 2010 by scenario.

Total system costs

In Figure 15 we show the relative total annual system costs across our scenarios, with *Emerging* the baseline. These annualised costs include all investment and operational expenditure throughout the energy system as represented by UKTM, i.e. they capture capital and maintenance costs as well as fuels costs. They do not include costs associated with the policies required to drive some of the energy service demand reductions.

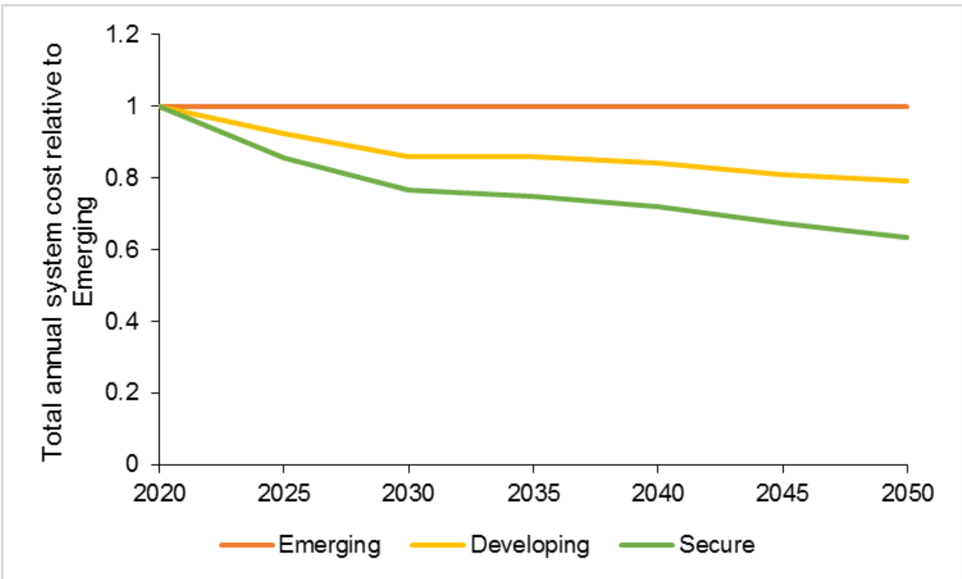

Figure 15. Total annual system cost relative to Emerging. This includes all investment and operational costs of the UK energy system included within UKTM.

As was demonstrated in the CREDS Low Energy Demand report, lower energy service demands enable a smaller energy system (e.g. fewer wind turbines and electric vehicles) and so it is not surprising that *Developing* and *Secure* offer a lower cost transition than *Emerging*. By 2050, *Developing* is ~20% cheaper than *Emerging* while *Secure* is almost 40% more cost effective. On top of these savings, the more rapid phase out of oil and gas from *Developing* and *Secure* also reduces the UK's exposure to global fossil fuel markets and any future price spikes, thereby ensuring a less volatile and cost effective supply of energy, i.e. greater energy security.