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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 countrier natural

The Levers of UK Energy Independence

As described previously, the UK is currently heavily dependent

Transport

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

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]ɸ ¢Kl·ű ăűdzŘèΩă {KλŦű l·yŘ ¢Ŋl·ƴãŦƻŊϒ LJl·űKǿl·èă ăŜű ƻdzű ŦdzűdzŊŜă űKl·ű 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 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 ŎI·ǋă ǿKƛŎK I·ǋŜ ōI·űűŜǋè ŜƭŜŎűǋƛŎ ŦǋƻΥ ǋƻǳƎKƭè űƻŘI·èΩă ¦Y 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

[8] All data in this paragraph taken from https://www.carbonbrief.org/guest-post-how-the-energy

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 ůKŜ ¦Y0ă ŘƧYŜăůλŎ ŎI·ŃŏƧy ōdzŘƎŜůă I·yŘ yŜů-zero greenhouse gas emissions target by 2050.

Pathways to an Energy Independent UK

Total UK Oil and Natural gas Demand

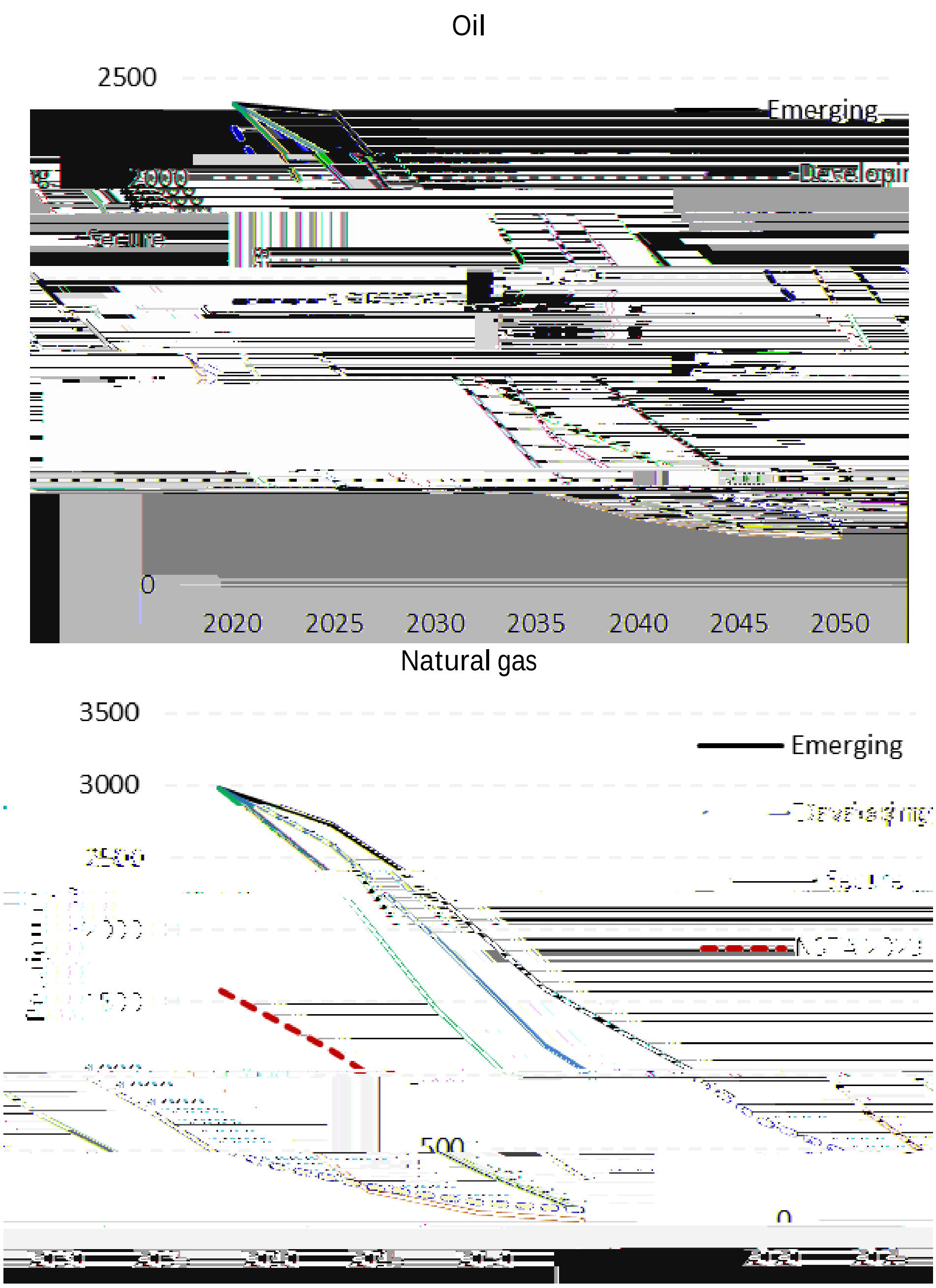

Figure 3. Oil (top panel) and natural gas (bottom panel) demand from the UK energy system in our scenarios compared with NSTA projections of production updated in February 2023

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

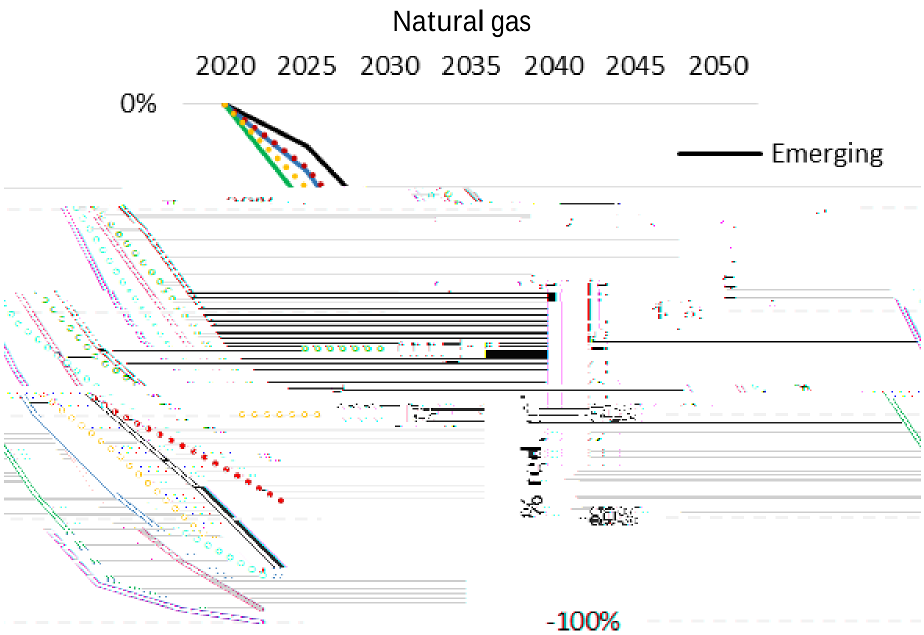

Figure 4. Change in oil (top panel) and natural gas (bottom panel) demand from the whole UK energy system in our scenarios compared with CCC Balanced Pathway (BP) and Tailwinds (TW).

In Figure 4 we compare total oil (top panel) and natural gas (bottom panel) demand pathways for ůKŜ ¦Yă ŜyŜ݃è system. Here we see that for oil and gas, at least until 2035, our *Emerging* and *Developing* scenarios are broadly in ŕyŜ øŀůK ůKŜ ///ŀă . t 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]).

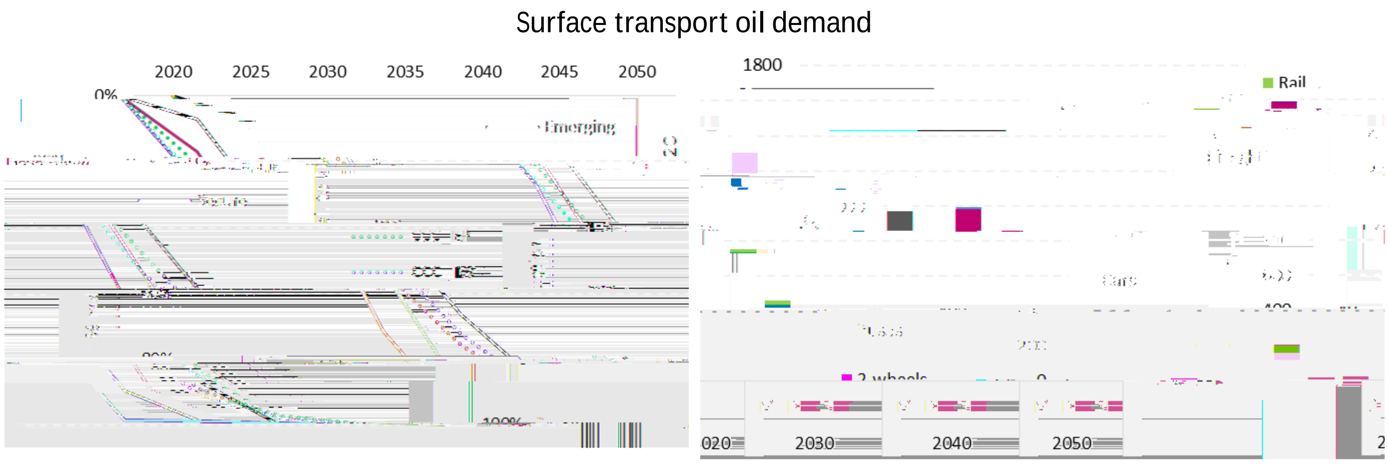

Figure 5. Change in oil demand in surface transport in our scenarios compared with CCC BP and TW (left panel) and sub-sector oil demands across our scenarios (right panel). Here Emerging is EM, Developing is DE and Secure is SE.

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.

Residential sector natural gas demand

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 ¦Y΍ă Kƻ YŜă ōè 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 ǘKŜ ¦Y΍ă ⅣŜăλŘŜƴǘλl·ƒ ăŜŎǘƻⅣ

more ambitious than their CCC counterparts. The vast majority of gas consumption is phased out by 2035 (*Emerging* and *Developing*

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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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 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.

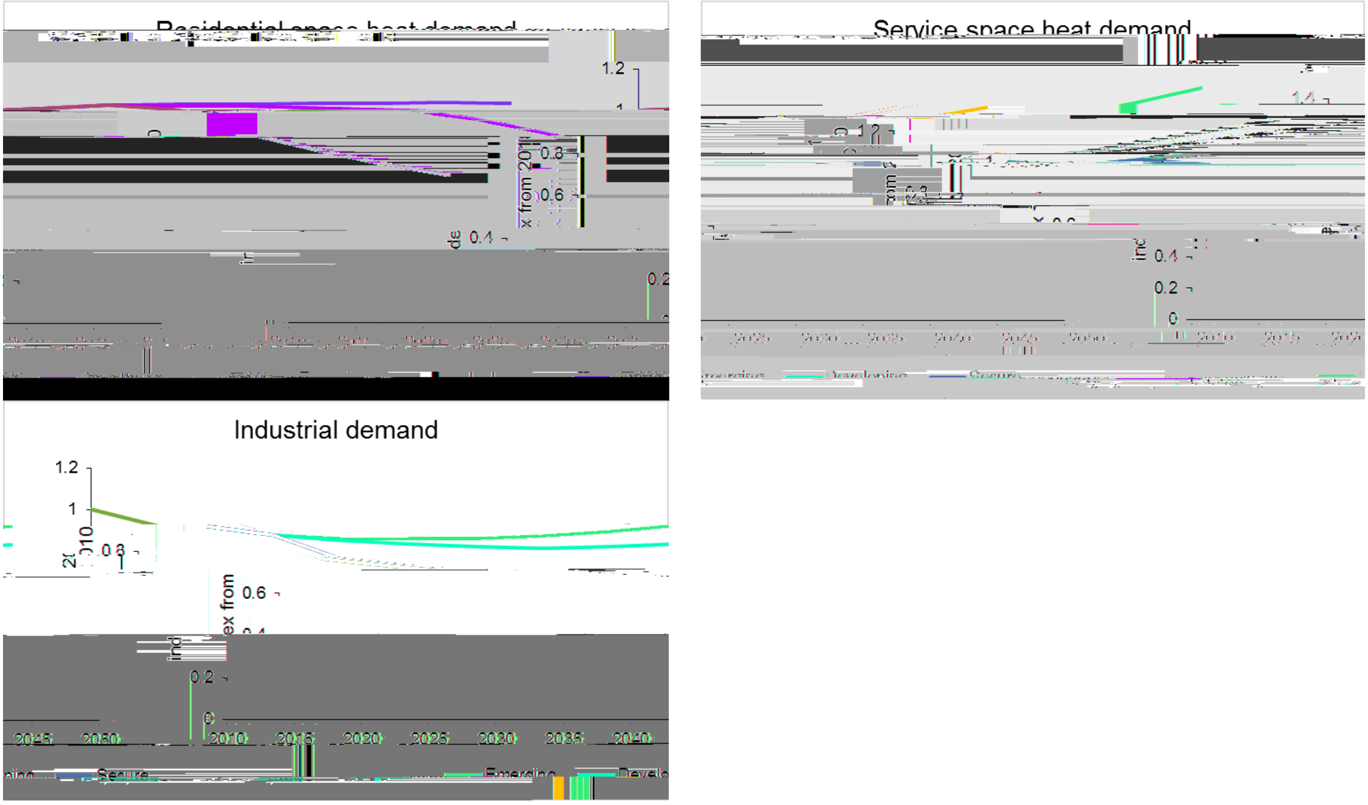

Figure 14. Key energy service demands across the residential, service and industrial sectors. Pathways are relative change in demand from 2010 by scenario.

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.

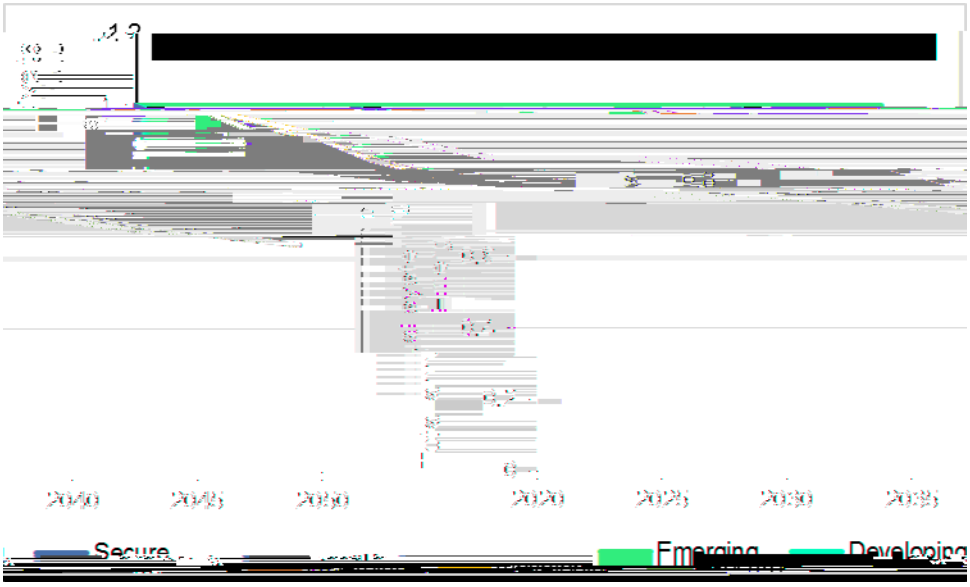

Figure 15. Total annual system cost relative to Emerging. This includes all investment and operational costs of the UK energy system included within UKTM.

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 ǘKŜ ¦ YΩă ŜÈLJƨădzǁŜ ǘƨ ∃ſƨōŀ·ſ ŦƨăǎʎſŦdzŜſ Y˙ŀ·ǁʅŜǘă ŀ·yŘ any future price spikes, thereby ensuring a less volatile and cost effective supply of energy, i.e. greater energy security.