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The UK's contribution to a Paris-consistent global emissions reduction pathway

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Contents

Executive Summary

This report presents analysis which outlines the extent to which the UK could be an international leader in greenhouse gas emissions reduction efforts to meet the 2015 Paris Agreement long-term temperature goal, which is to limit global warming to "well below" 2°C and pursue efforts towards a 1.5°C limit.

The report considers three different strands of analysis relevant to this question. The first is the UK's recent achievements in emissions reductions, when compared to other countries, as an indicator of its ability to make rapid future emissions reductions. The second is the relative effort of more developed regions such as the UK, compared to other less developed regions, in modelled low-carbon scenarios consistent with achieving the Paris goal. The third are the current pledges and ambitions made by different countries, as well as their own national-level modelling of deep mitigation pathways, an indicator of their own degree of ambition and capability.

The first strand of analysis highlights that the UK has led the world in energy-sector CO_2 emissions reductions, which form the majority of its greenhouse gas emissions, in recent years. The UK has achieved this primarily through decarbonising its energy supply faster than other countries, primarily because of a rapid decarbonisation of its power sector, with a shift away from coal and towards low-carbon generation sources such as wind and solar. There remains considerable room for the UK to further decarbonise its economy, since it has lagged many countries' performance in other sectors, notably transport, buildings and agriculture. The UK's relatively strong institutional regulatory and policy framework make it well placed to replicate other countries' efforts in decarbonising their demand (transport, buildings and agriculture) sectors, as well as further decarbonising its power sector.

The second strand of analysis demonstrates that, in modelled low-carbon pathway scenarios that seek to minimize the global cost of mitigation, there tends to be higher per person emissions in developed regions (such as the UK) in many well below 2°C scenarios by 2050, compared to less developed regions. In 1.5°C scenarios, there is a convergence amongst all regions to highly decarbonised, approximately net zero CO_2, economies, by 2050. These results must be treated with caution, since they only tend to take into account theoretical mitigation cost differences between regions and do not account for differences in institutional capacity and access to finance, which might hamper less developed regions from realizing their (theoretically cheaper) mitigation options.

The third strand of the analysis highlights that the EU's current plans would see it achieve lower levels of per person emissions by 2050 when compared to Japan and the USA (two other major economies which also have 2050 targets). In addition, it suggests that certain countries and regions (including the EU and UK), could feasibly reach very low (<1.5tCO_2 per person) emissions by 2050, whereas other regions might be less likely to do so, on the strength of their current ambitions, as well as on the basis of a number of challenges that they currently face, including a heavy reliance on fossil fuels.

Taken together, these analytical strands suggest the UK can be part of a leading group of countries in reducing emissions towards Paris-consistent climate goals, owing to its recent emissions reduction performance, current level of ambition and its own identification of feasible, deep decarbonisation pathways. However, a number of further considerations must be taken into account, including detailed sectoral analysis of UK mitigation potential, in particular around the energy demand sectors which have so far lagged both the UK's power sector, as well as the performance of other international leaders in these sectors.

1 Introduction

1.1 Context

The UK's 2008 Climate Change Act (UK Government, 2008), which enshrines in primary legislation the target to reduce 2050 greenhouse gas emissions by at least 80% compared to 1990 levels, was passed at a time when there was widespread international acknowledgement of the need to limit global warming to around 2°C above pre-industrial levels, to avoid dangerous levels of climate change.

The Paris Agreement of 2015 reflected the growing evidence base on the increased risks of climate change, and the consequent need to limit global warming to "well below" 2°C and pursue efforts towards a 1.5°C limit (UNFCCC, 2015). The IPCC's Special Report on Global Warming of 1.5°C (hereafter IPCC-SR1.5) (IPCC, 2018), explicitly requested by the Paris Agreement and published in October 2018, confirms the significant additional climate risks of a 2°C warmer world compared to a 1.5°C warmer world.

It is therefore timely and appropriate to consider what the UK's contribution to the Paris Agreement's goal should be, and whether this contribution requires a revision of the UK's emissions reduction target. In October 2018, the UK, Scottish and Welsh governments (BEIS, 2018) asked the Committee on Climate Change for its advice on whether to review the current 2050 target. As specified by the UK Climate Change Act 2008, any such changes should be based on a range of considerations including changes in "(i) scientific knowledge about climate change, or ii)European or international law or policy,". This underscores the importance of considering international circumstances, as is undertaken in this report.

1.2 Structure of the analysis

In Section 2, the analysis sets out the extent to which the UK has managed to reduce its greenhouse gas (GHG) emissions in recent years, compared to other countries and regions and the world as a whole. This shows the extent to which the UK has been, and could potentially continue to be, a leader in emissions reductions efforts.

In Section 3, the analysis explores a number of recent modelled low-carbon pathways scenarios which are broadly consistent with achieving the Paris Agreement's goal, both at a global as well as regional level. This helps demonstrate what might be required of different regions, principally in terms of emissions reductions and changes to their energy systems, in such deep decarbonisation scenarios.

In Section 4 the analysis compares the near-term and longer-term pledges and ambitions of different countries and regions, to understand which countries and regions are currently planning the most ambitious decarbonisation actions.

Section 5 briefly summarises the preceding analysis to indicate the extent to which the UK could realistically be considered a leader in future global efforts to achieve a Paris Agreement-consistent global low-carbon transition.

2 UK emissions reductions in a global context

2.1 Overall picture

The analysis that follows compares the UK's current emissions and historical emissions reduction performance with that of other countries and regions. The frame of analysis is in most cases per person emissions. Other frames (such as emissions per unit of economic output, i.e. per $ of GDP) are also possible. Emissions per person is the result of different factors, combined into a "Kaya" multiplicative identity (see for example CICERO, n.d.) which expresses emissions per person in terms of economic output per person, energy intensity of economic output, and emissions intensity of energy use. Mathematically it is written as follows (when considering CO_2 emissions):

CO_2/person = GDP/person * Energy / GDP * CO_2 / Energy

The analysis uses this Kaya framework (and explicitly shows Kaya factors for a range of countries) to consider emissions per person in terms of these different factors that make it up.

The focus is on comparing the UK to the world's top ten emitting countries[1], in addition to three key regional groupings (G20, OECD and EU28), and six other countries for comparison. These are three comparable EU countries (Spain, Italy and France), and three G20 Latin American countries (Argentina, Brazil and Chile). Together these countries and regions made up 77% of global greenhouse gas (GHG) emissions in 2015, as shown in Figure 1.

[1] Territorial CO_2 emissions from fossil fuels and industrial processes (FFI) as reported by the Global Carbon Project (Le Quéré et al., 2018)

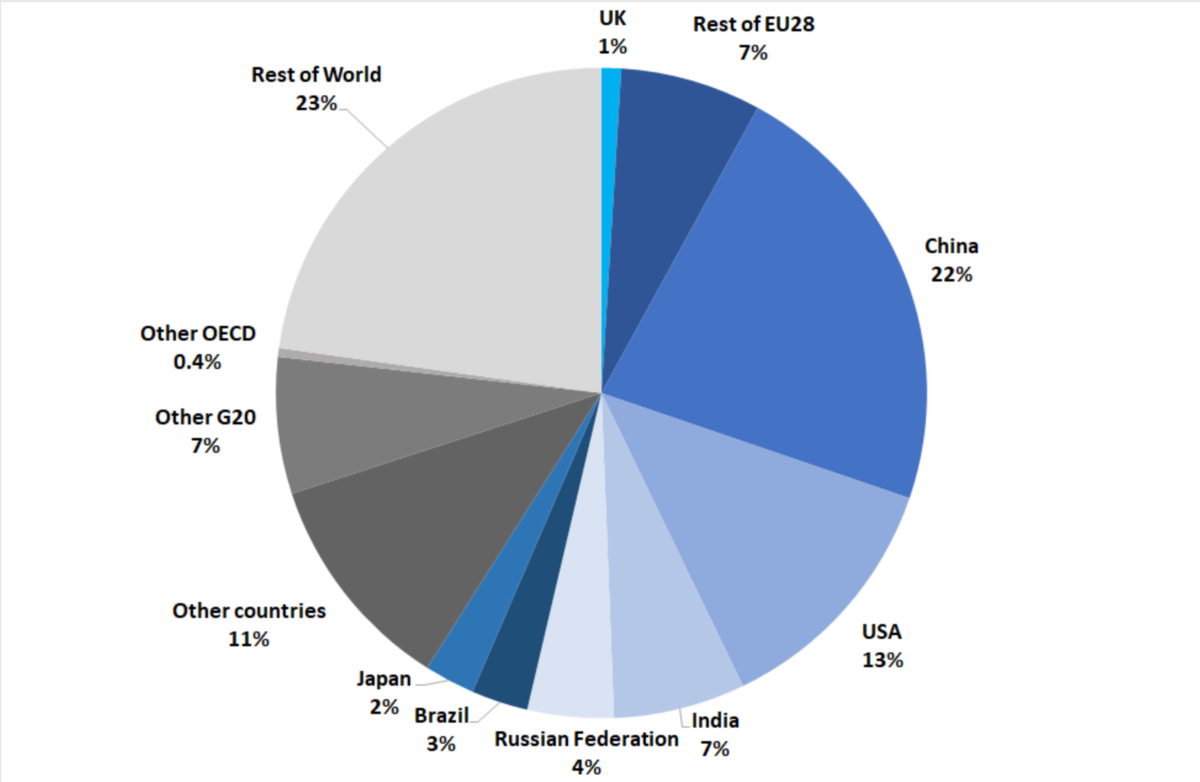

Figure 1 – Country and region share of global greenhouse gas emissions, 2015

Notes – "Other countries" refers to those countries in the figures in this Section which are shown individually (i.e. Canada, Iran, South Korea, Germany, Italy, France, Spain, Chile and Argentina); "Rest of G20" refers to those G20 countries not shown individually nor as part of the EU28 group (i.e. Australia, Mexico, Saudi Arabia, South Africa, Turkey); "Rest of OECD" refers to those OECD countries not shown as part of EU28 nor as part of G20 (i.e. Iceland, Israel, New Zealand, Norway, Switzerland); Rest of World" refers to those countries not shown in this Section, either individually or as part of the EU28, G20 or OECD groups. GHG emissions use Global Warming Potential 100 year (GWP_{100}) values from IPCC fourth assessment report (AR4) (IPCC, 2007) except for Agriculture, Land Use and Forestry (AFOLU) sectors, from FAO data which uses GWP_{100} values from IPCC second assessment report (AR2) (IPCC, 1995)

Source - Le Quéré et al. (2018), IEA (2018a), UNFCCC (n.d.), FAO (n.d.), World Bank (n.d.)

For each subsequent chart, the UK is shown in light blue, the world in red and the three country groupings (EU28, G20, OECD) in purple, with individual countries in navy blue. In addition, each chart shows (where appropriate) current values using the most recent dataset that covers all countries consistently. Hence, whilst for some countries even more recent data may be available, if this data isn't available for all countries it isn't included.

The UK has a significantly higher economic output per person than most other countries, at over two and a half times the world average. Yet its GHG emissions per person are only slightly above the world average (Figure 2). The UK has approximately the same economic output per person as the rest of the OECD, but 37% lower emissions per person. Its economic output per person is 7% higher than that of the EU as a whole, whilst its emissions per person are 4% lower. Comparing the UK to the world's two largest emitters (China and the USA), the UK has lower emissions per person than China, in spite of having almost three times the economic output per person, and the UK has less than half the emissions per person of the USA.

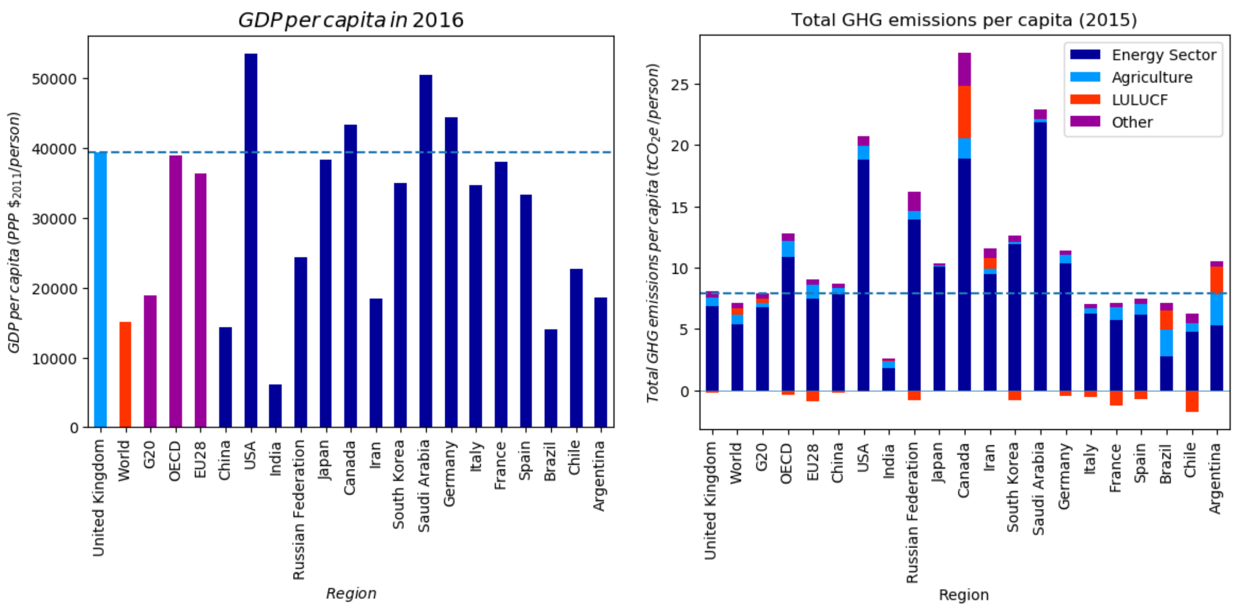

Figure 2 – GDP per person (2016) and GHG emissions per person (2015)

Notes – Land Use, Land Use Change and Forestry (LULUCF) emissions sourced from UN Food and Agriculture Organisation (FAO) – it should be noted that these emissions tend to be subject to high uncertainty and can vary greatly between different sources.

Source - Le Quéré et al. (2018), IEA (2018a), UNFCCC (n.d.), FAO (n.d.), World Bank (n.d.)

These emissions are expressed on a territorial basis, which means they do not take into account the emissions abroad resulting from the UK import of products and services. The UK's per person CO_2 emissions from the energy sector, on this "consumption" basis, are about 30% higher than its territorial emissions. As explained in Section 2.3.2, a key reason for the discrepancy between the UK's territorial and consumption-based emissions is the UK's relatively low share of industrial value added in total economic output, and low energy-intensity of its industrial sector mix of activities, indicating that it is a more service-based economy and one which produces higher value-added, less energy-intensive (and emissions-intensive) products, leading to a relatively high contribution of these products in imports to the UK. On this consumption basis the UK's emissions per person are slightly higher than the EU average and higher than China's, even though they are significantly below the OECD average (Figure 3).

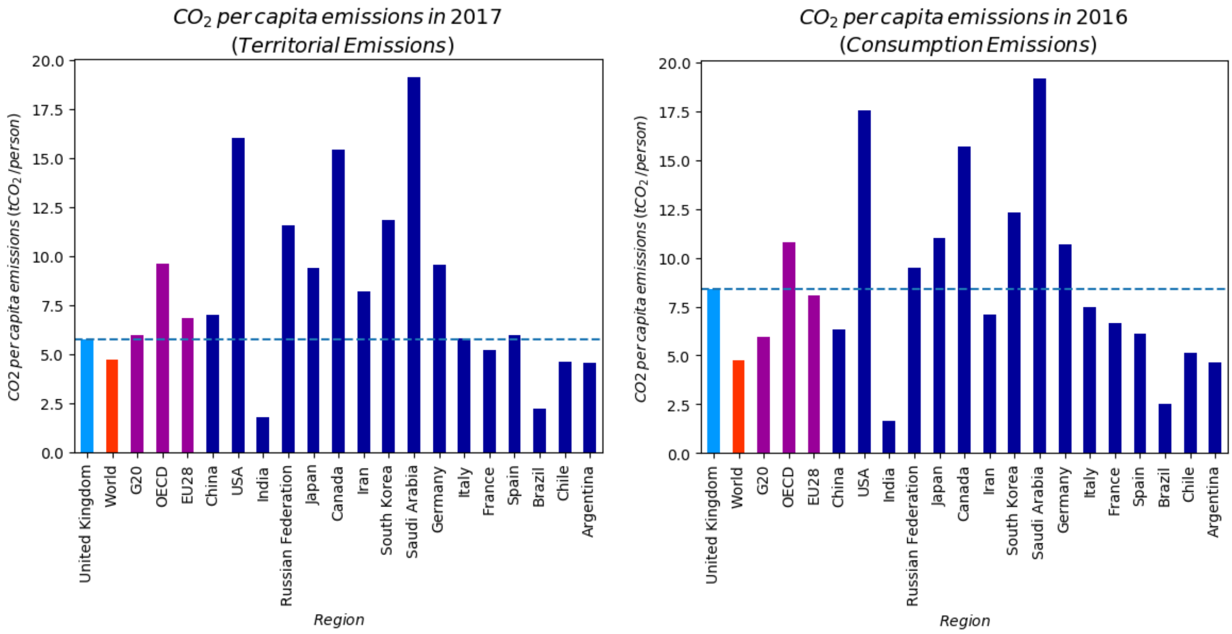

Figure 3 – CO_2 emissions per person on territorial (2017) and consumption (2016) basis

Notes – CO_2 emissions are for the energy sector, which includes the combustion of fossil fuels as well as emissions from industrial processes

Source - Le Quéré et al. (2018), World Bank (n.d.)

On both territorial and consumption bases, the UK has been reducing its CO_2 emissions per person more rapidly than many other countries and regions over recent years, as shown in Figure 4. On a territorial basis, the UK has outperformed almost all other countries since 2012, decarbonising at almost four times the rate of the EU as a whole, and significantly faster than any other major developed economy. On a consumption basis, the UK has decarbonised faster than the EU since 2011 and outperformed most other countries. As such, the UK's emissions reductions have not simply been the result of "off-shoring" energy- and emissions-intensive industrial manufacturing activities. Rather, as explained later in this section, they have been driven by a decarbonization in the UK's energy supply, primarily from its power sector.

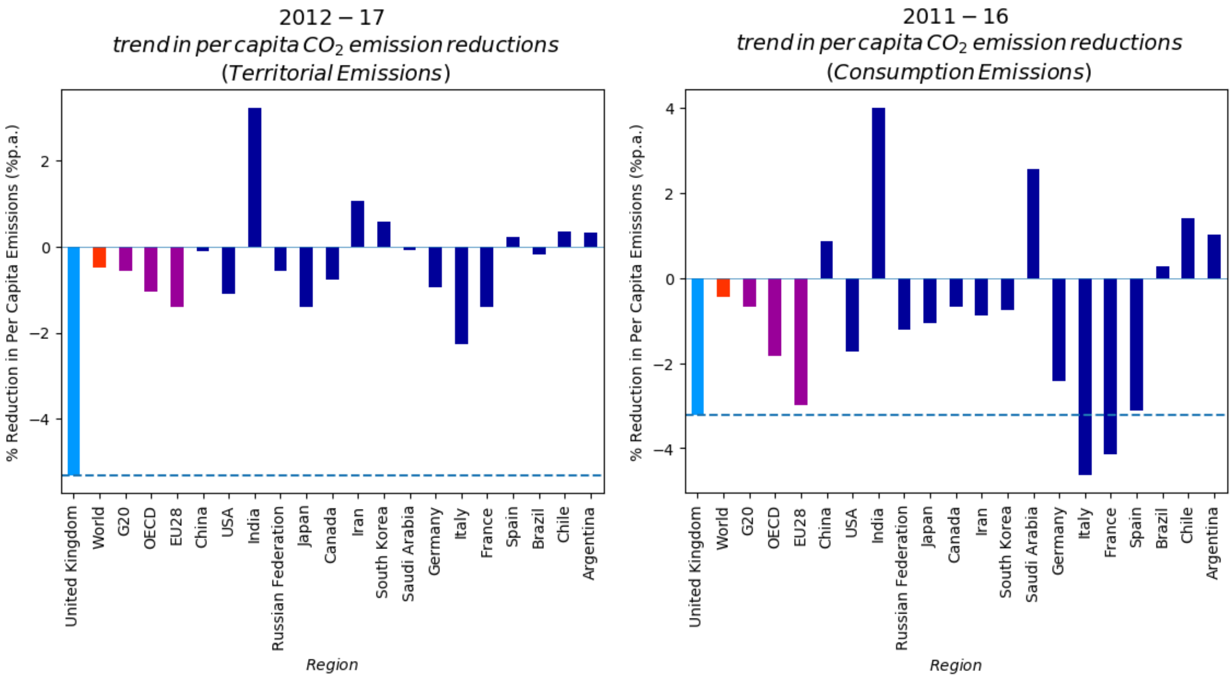

Figure 4 – Five year trend in CO_2 emissions per person on territorial and consumption bases

Notes – CO_2 emissions are for the energy sector, which includes the combustion of fossil fuels as well as emissions from industrial processes

Source - Le Quéré et al. (2018), World Bank (n.d.)

These short term-trends in emissions reductions in both territorial and consumption-based emissions represent an acceleration compared to the longer-term trends, as shown in Figure 5. Since 1990, the UK has reduced its territorial CO_2 emissions per person by just over 2% per year on average (compared to just over 5% per year over the period 2012-2017). However, this represents a rapid CO_2 emissions reduction rate compared to almost all other regions. It is almost double the level for the whole EU region, more than four times as fast as the OECD, and a marked contrast with the global increase in CO_2 emissions per person of 0.5% per year over this period. Since 1990, the UK's consumption-based emissions have also fallen, although at only about half the rate of its territorial emissions. Nevertheless, the UK has also been amongst the leading countries on this metric, with only the Russian Federation, which experienced a sharp economic contraction in the early 1990s, outpacing the UK over this longer-term period.

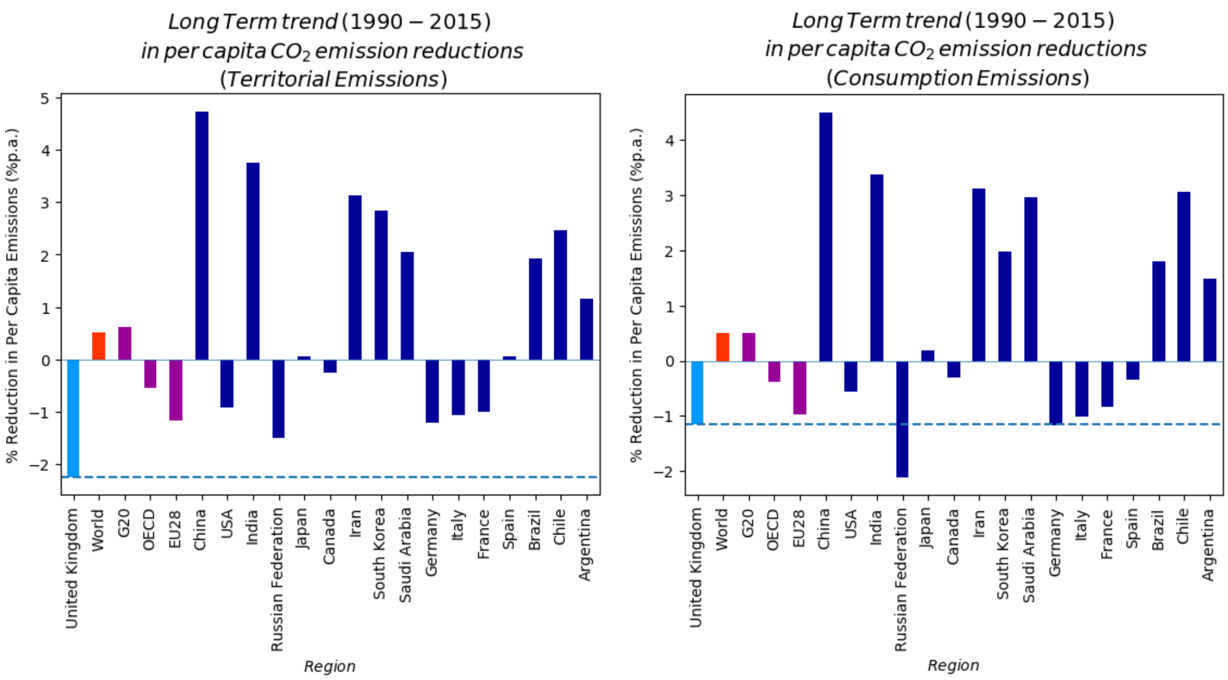

Figure 5 – 1990 -2015 trend in CO_2 emissions per person on territorial and consumption bases

Notes – CO_2 emissions are for the energy sector, which includes the combustion of fossil fuels as well as emissions from industrial processes

Source - Le Quéré et al. (2018), World Bank (n.d.)

2.2 Drivers of energy sector CO_2 emissions reductions in the UK

The UK's relatively low CO_2 emissions per unit of economic output is primarily a result of its low final energy intensity of GDP, since its CO_2 emissions intensity of final energy is approximately in line with other countries (Figure 6). Specifically, the UK has almost the same CO_2 emissions intensity of final energy as the whole EU, almost 10% lower than the OECD and 17% lower than the world average. By contrast, its final energy per unit of GDP is almost 20% lower than the EU, more than 30% lower than the OECD and more than 40% lower than the world average.

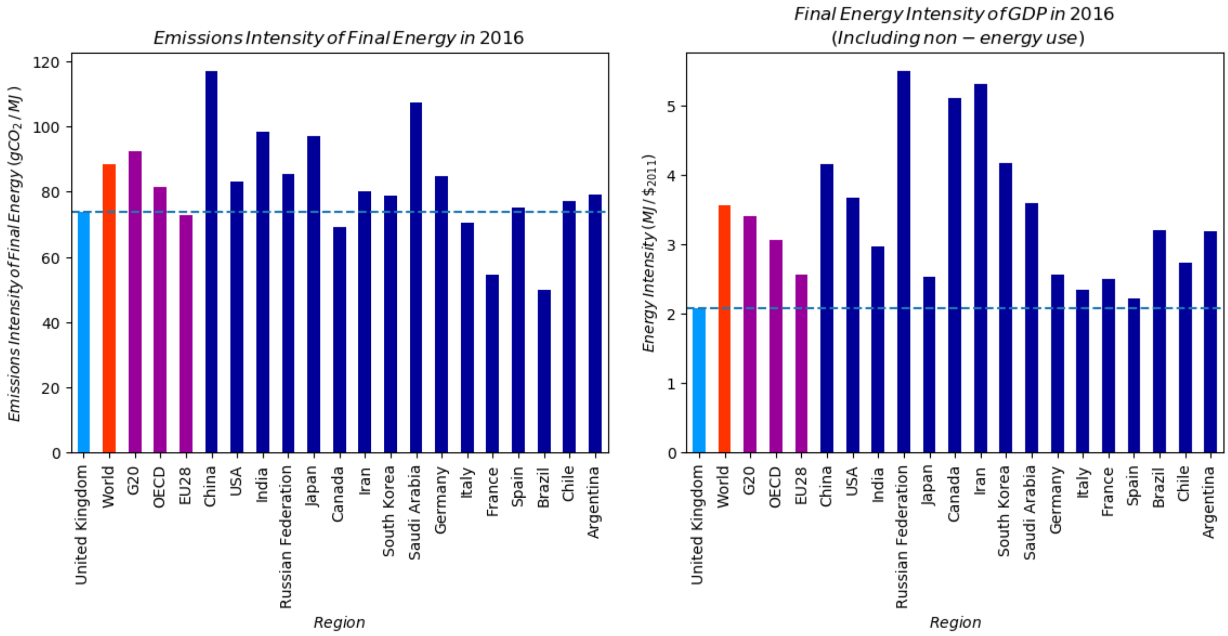

Figure 6 – CO_2 emissions intensity of final energy (2016) and final energy intensity of GDP (2016)

Notes – CO_2 emissions are for the energy sector, which includes the combustion of fossil fuels as well as emissions from industrial processes. GDP on Purchasing Power Parity basis

Source - Le Quéré et al. (2018), World Bank (n.d.), IEA (2018a)

In recent years the UK has made exceptionally rapid progress in reducing its CO_2 emissions intensity of final energy, whilst reducing its final energy intensity of GDP in line with the world average (Figure 7). In fact the UK has reduced its CO_2 emissions intensity of final energy at about four times the rate of the EU as a whole, and almost eight times faster than the world.

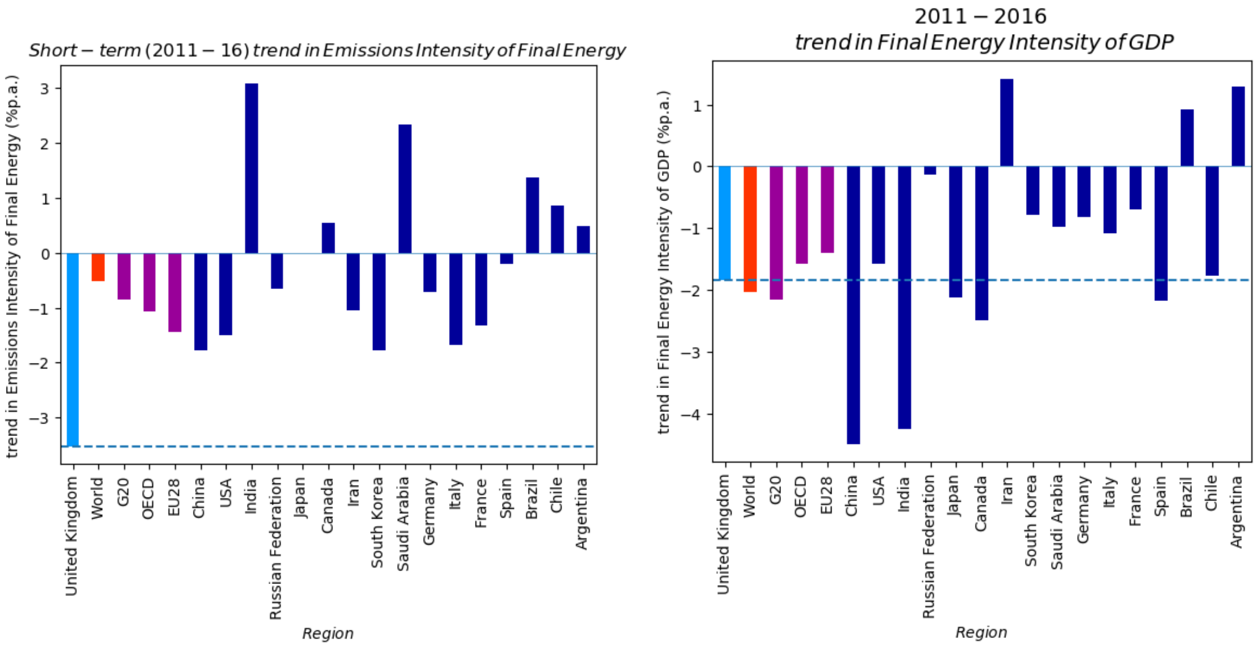

Figure 7 – Five year trends in CO_2 emissions intensity of final energy and final energy intensity of GDP

Notes – CO_2 emissions are for the energy sector, which includes the combustion of fossil fuels as well as emissions from industrial processes. GDP on Purchasing Power Parity basis.

Source - Le Quéré et al. (2018), IEA (2018a)

In summary there has been a rapid fall in CO_2 emissions intensity and subsequent reduction in CO_2 emissions in the UK in recent years. As shown in Figure 8, this represents a significant development from the pattern of CO_2 emissions to around 2010, where falling energy intensity of economic output either offset or more-than-offset economic growth to deliver flat (to around 2000) and then steadily falling (2000-2010) emissions, with a fairly constant CO_2 emissions intensity of final energy. Since 2010, a marked fall in CO_2 emissions intensity of final energy has been the primary driver for the UK's leading emissions-reduction performance (rather than, as indicated earlier, a decline in industrial manufacturing). As explained in Section 3.3, a rapid reduction in CO_2 emissions intensity of energy is a critical driver of emissions reductions in modelled scenarios which meet the Paris goal. The UK's recent experience in leading on this metric is therefore a useful indication of its ability to lead in the future.

By contrast, the world as a whole has seen a lower rate of reduction in the energy intensity of its economic output than the UK, combined with a lack of recent reductions in CO_2 emissions intensity of final energy, to result in steadily increasing global CO_2 emissions over the last 25 years. As shown by Figure 8, this global average picture masks regional differences, where some major economies (USA, EU, Russia) have seen a fall in their CO_2 emissions intensity of final energy (although even in these cases, not to such a dramatic degree as in the UK) whilst other major economies (Japan, China, India, Brazil) have seen a rise. Of these latter countries, only in the case of Japan has this been more than offset by a reduction in CO_2 emissions intensity of economic output, to deliver emissions reductions.

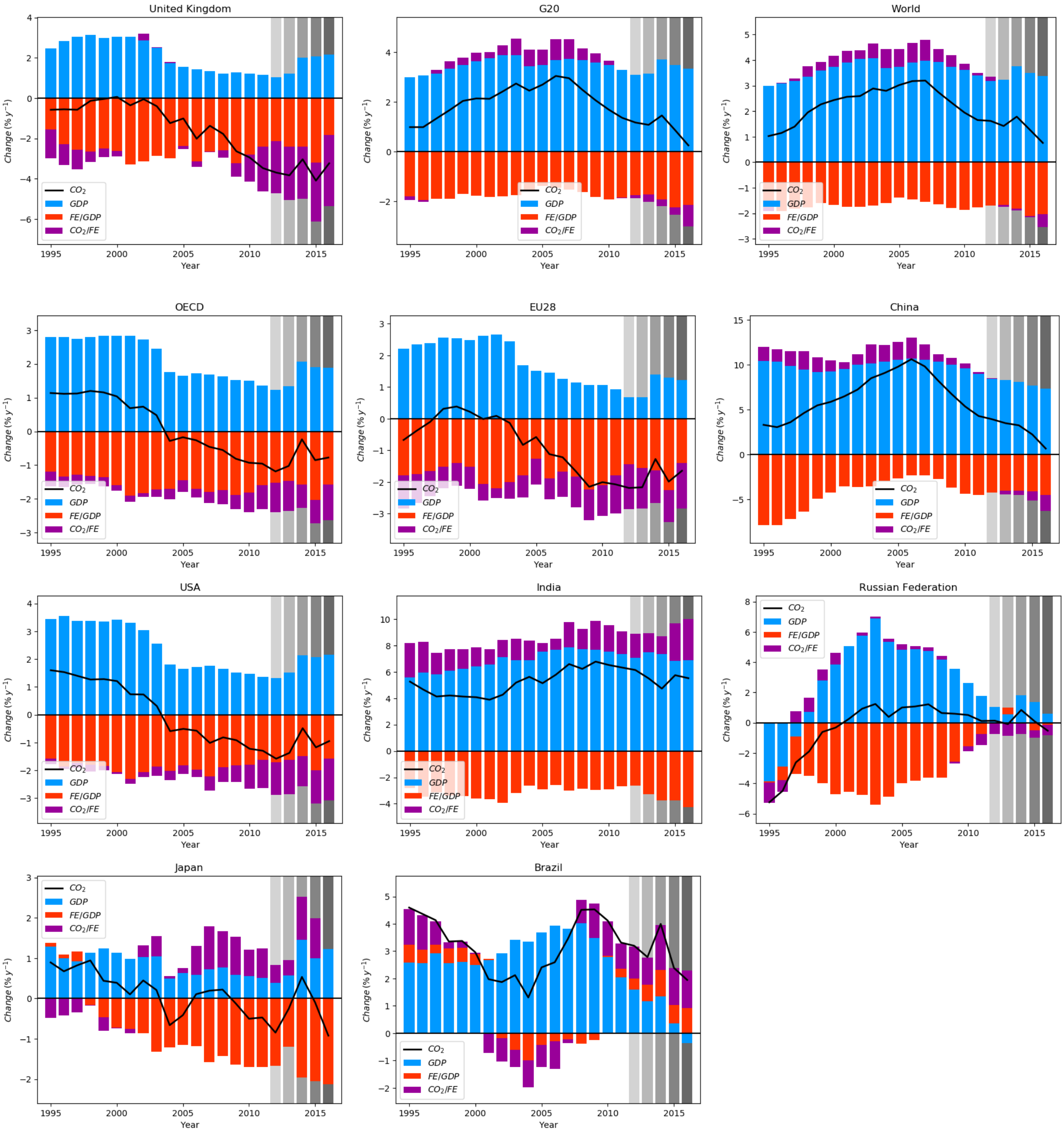

Figure 8 – CO_2 emissions Kaya identities for UK and selected major emitters, 1995-2016

Notes – Kaya identity as used here disaggregates energy sector annual CO_2 emissions changes into annual changes in CO_2 per unit of Final Energy (CO_2/FE), annual changes in Final Energy per unit of GDP (FE/GDP) and annual changes in GDP. Kaya identity can also include a separate term for changes in population, but in this case population changes are included in GDP changes. CO_2 emissions for the energy sector include the combustion of fossil fuels as well as emissions from industrial processes. GDP on Purchasing Power Parity basis. The data is smoothed with a 10-year window to show longer-term trends, and the grey shading from 2011–2016 represents a diminishing window length as 2016 is approached.

Source – CICERO (n.d.), Le Quéré et al. (2018), World Bank (n.d.), IEA (2018a)

2.3 Sectoral emissions reductions

Figure 9 compares CO_2 emissions per person in each major sector, demonstrating that the UK has relatively low power sector CO_2 emissions compared to the OECD, EU and world as a whole, as well as compared to many less developed countries.

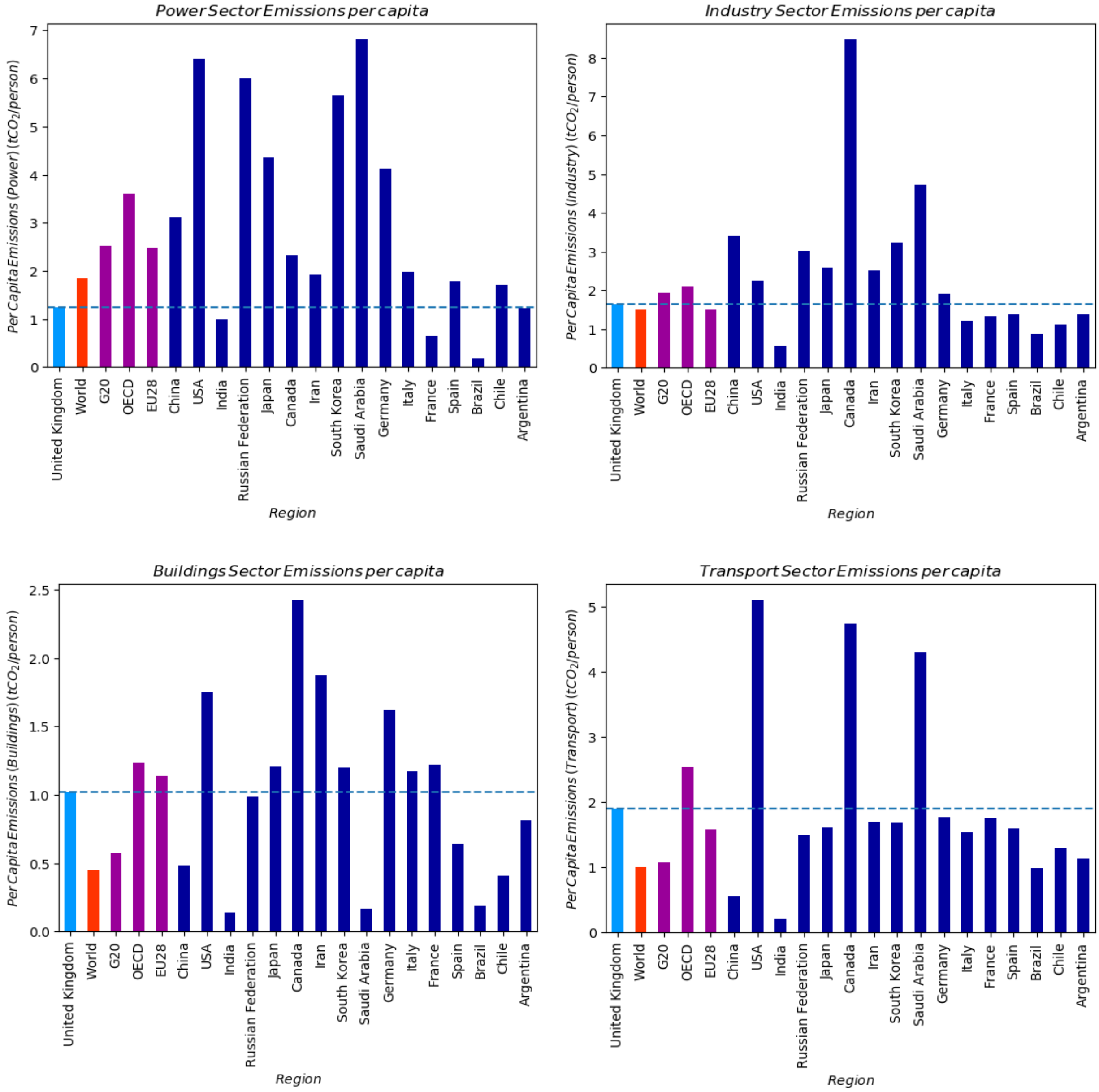

Figure 9 – CO_2 emissions per person for each major energy sector (2016)

Notes – y-axis (i.e. CO_2 emissions per person) scales are different for different panels.

Source - EDGAR JRC 4.3.2 (Maenhout-Janssens et al., 2017), IEA (2018b), BEIS (n.d.)

The UK's industrial emissions per person are approximately in line with the world average and EU as a whole. By contrast, the UK's buildings[2] emissions per person are more than twice the world average, although less than the OECD and EU as whole. The UK's transport emissions per person are just less than twice the world average, and although 20% lower than the OECD, about they are above the EU average. The UK's buildings emissions per person are broadly similar to the EU average and OECD averages. However, the UK's transport sector emissions per person are higher than all other countries and regions shown, apart from the OECD as a whole[3], Canada, the USA and Saudi Arabia.

Furthermore, as shown in Figure 10, there has been very rapid decarbonisation of the UK power sector, far outstripping other countries, whilst the UK's industrial emissions per person have also fallen relatively fast. By contrast, the UK's buildings emissions per person have only fallen in line with the world average, and at about half the rate of the EU as a whole, whilst transport emissions per person have barely changed, in contrast with relatively rapid reductions in the EU as a whole.

[2] Building heating demands can vary greatly between countries with different climates, so a direct comparison only on the basis of emissions masks these differing demands.

[3] The OECD average is significantly influenced by the USA and Canada. Without them, the OECD average falls from 2.54tCO_2/capita to 1.58tCO_2/capita i.e. below the UK and EU levels.

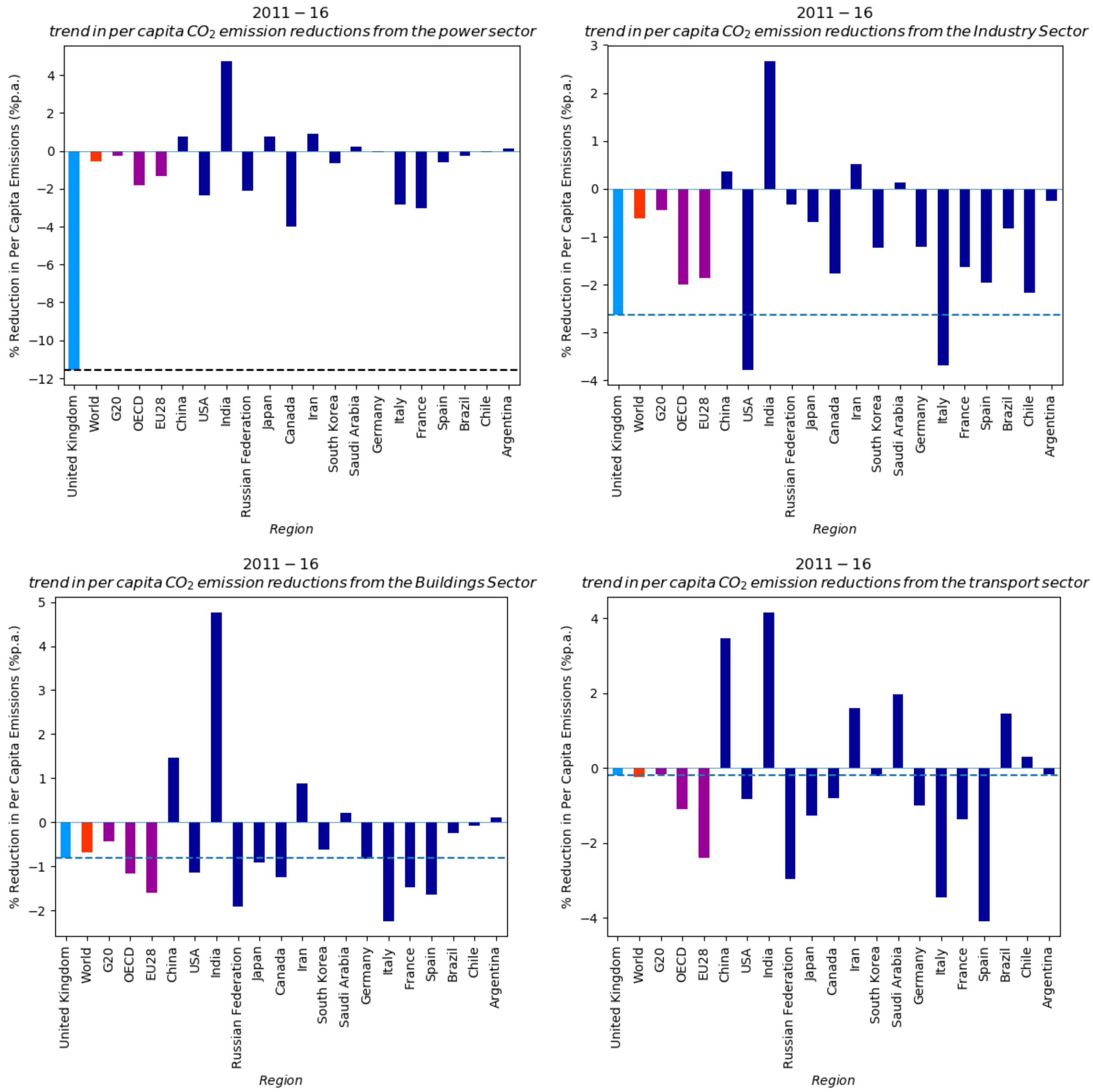

Figure 10 – Five year trend in CO_2 emissions per person for each major energy sector

Source: EDGAR JRC 4.3.2 (Maenhout-Janssens et al., 2017), IEA (2018b), BEIS (n.d.)

The following sub-sections discuss each major energy sector in turn.

2.3.1 Power sector

The UK's rapid reduction in CO_2 emissions intensity in recent years has been largely driven by decarbonisation of its power sector. The UK's CO_2 intensity of electricity generation has fallen to such an extent that it now has one of the least CO_2-intensive power sectors in the world (Staffell, 2017). There have been two major drivers of this electricity generation decarbonisation. The first is a rapid reduction in the share of coal-fired power generation, which is the most CO_2-intensive electricity source. At less than 10% of total generation, the UK now has one of the world's lowest shares of coal in its power sector, with an average rate of reduction of more than 6 percentage points per year since 2012, as shown in Figure 11.

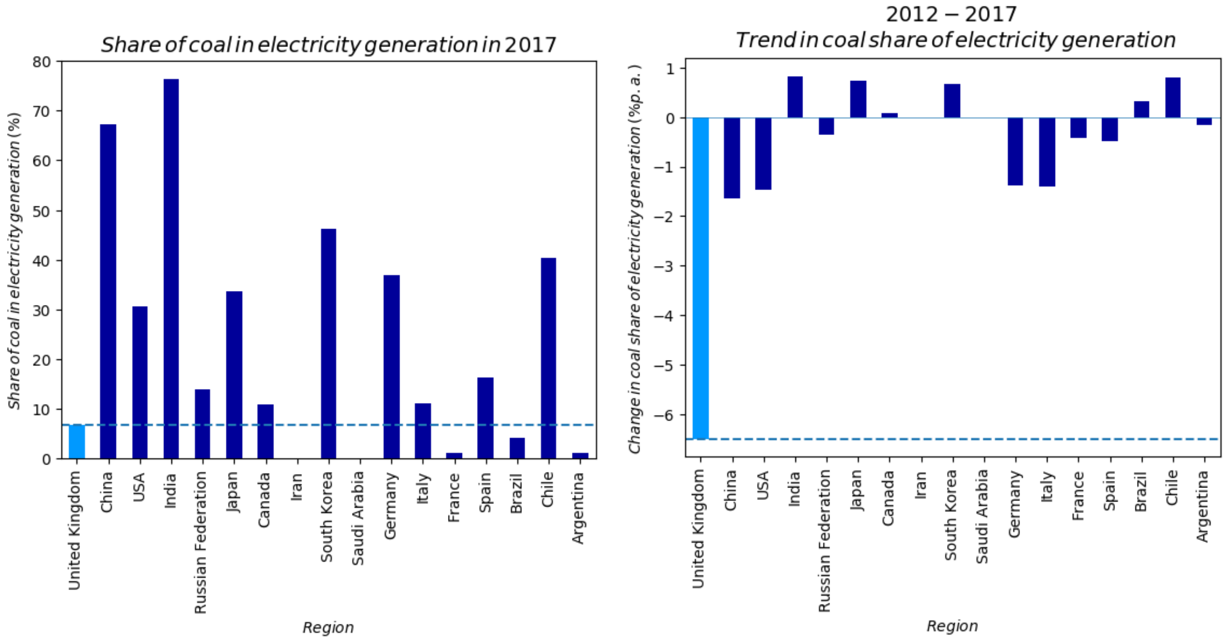

Figure 11 – Share of coal in electricity generation (2012 and five year trend)

Notes – Data from Staffell et al. (2018) available for a more recent period (i.e. to 2017) than for most of the previous analysis.

Source – Staffell et al. (2018)

In addition to the UK's reduced share of coal-fired generation, there has also been a rapid rate of growth in low-carbon generation sources, mainly solar photovoltaics and wind power. Figure 12 shows that, as a share of total generation, growth in low-carbon power in the UK has outpaced all other countries and regions shown, at more than double the EU average rate of growth and around seven times the world average rate. However, as of 2016 the UK still had less than half its power generated by low-carbon sources. The UK still has the capacity to further reduce its power sector CO_2 intensity (and therefore economy-wide CO_2 emissions intensity of final energy) to a considerable extent, by increasing its share of low-carbon sources so that they make up the majority of its generation.

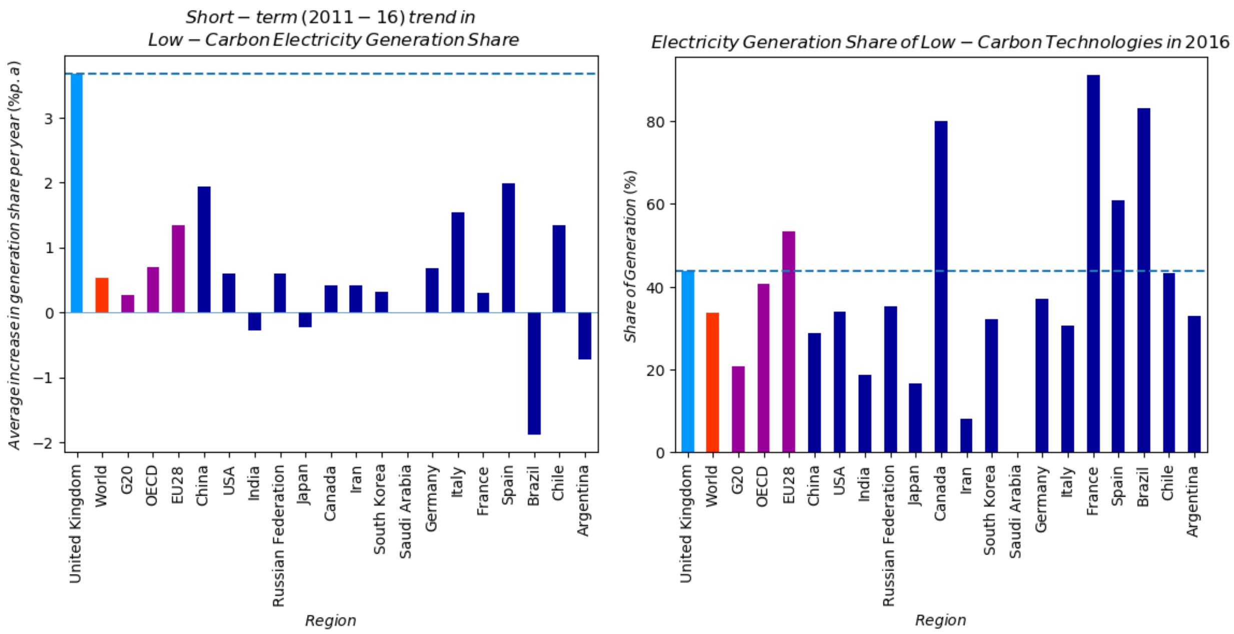

Figure 12 – Low-carbon electricity generation share of total (2016 and five year trend)

Notes – Low-carbon sources included are nuclear, hydro, biomass, solar and wind

Source - IEA (2018a)

2.3.2 Industry sector

As discussed in Section 2.1, to a large extent the discrepancy between territorial and consumption-based CO_2 emissions in the UK reflects its relatively low industrial share of total economic output, with the UK a more service-based economy compared to the global average, as well as the rest of the EU, as shown in Figure 13.

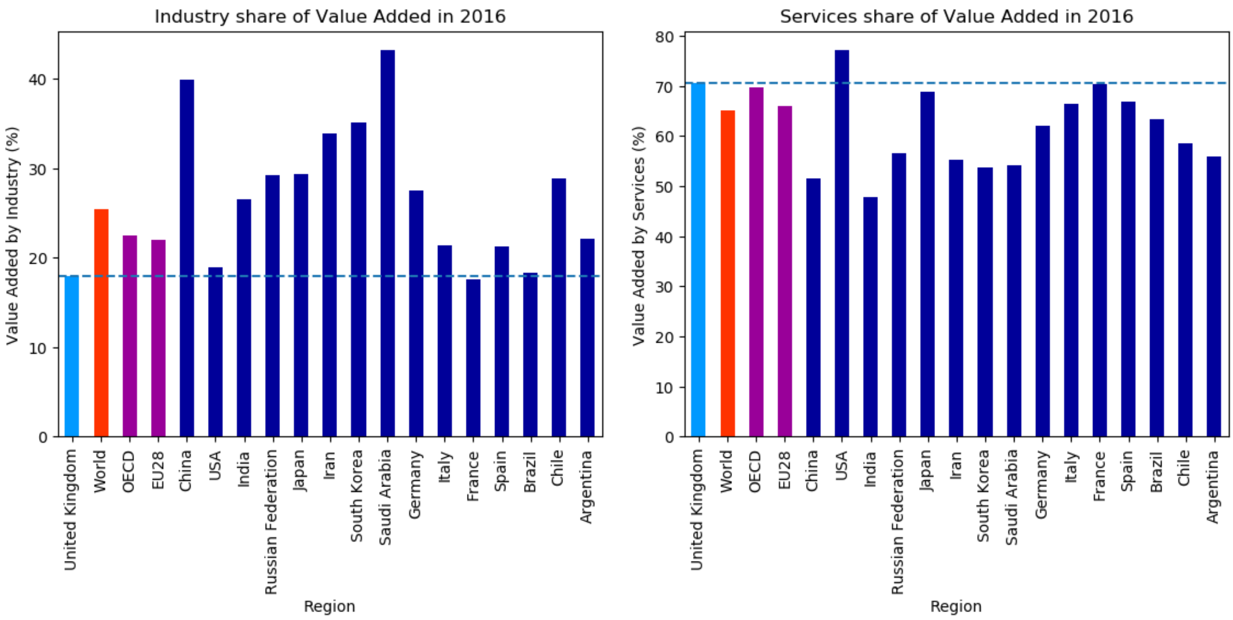

Figure 13 – Industry and Services value added as share of total economic output, 2016

Notes - The industrial sector corresponds to ISIC divisions 10-45, and the services sector corresponds to ISIC divisions 50-99, using ISIC revision 3.

Source - World Bank (n.d.)

It is important to note that, whilst relatively small, the UK's industrial share of economic output has remained unchanged since 2011, as shown in Figure 14. So the UK's rapid reduction in CO_2 emissions per person since 2011 has not been the result of it "off-shoring" its industrial sector. Looking at the longer-term trend since 2000 (also shown in Figure 14), the UK has had a higher average annual rate of reduction in its industrial share of output compared to many other countries, but at an average of less than 0.3 percentage points per year, this is far below either its long-term territorial (-2% per year) or consumption-based (-1% per year) trends in emissions reductions. This suggests that over both timescales, the UK's emissions reductions have not been driven by a reduction in the contribution that total industrial output makes to total economic output.

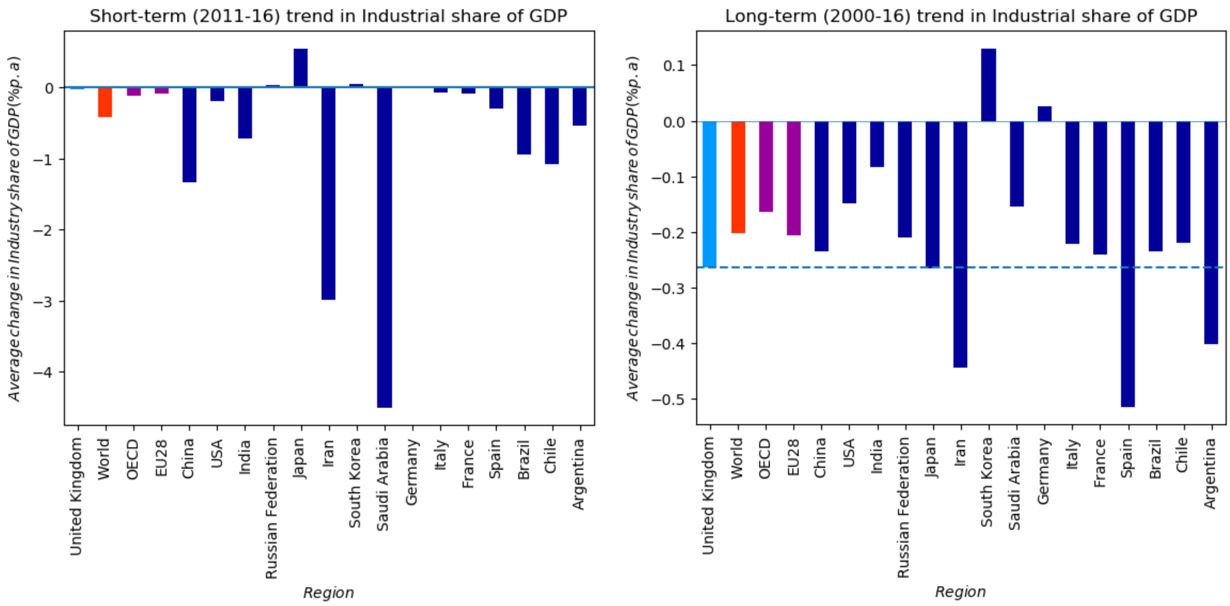

Figure 14 – Trends in Industrial share of total output, 2011-2016 and 2000-2016

Notes – The industrial sector corresponds to ISIC divisions 10-45, and the services sector corresponds to ISIC divisions 50-99, using ISIC revision 3; Consistent country data to period before 2000 unavailable; GDP on Purchasing Power Parity basis.

Source - World Bank (n.d.)

In economic value terms, the UK has a relatively high industrial output per capita, at almost twice the world average, though between 10 and 20% below the EU and OECD as a whole, as shown in Figure 15. The UK also has a less emissions-intensive industrial sector compared to the world average, indicating a very different mix of industrial activities to the world as a whole.

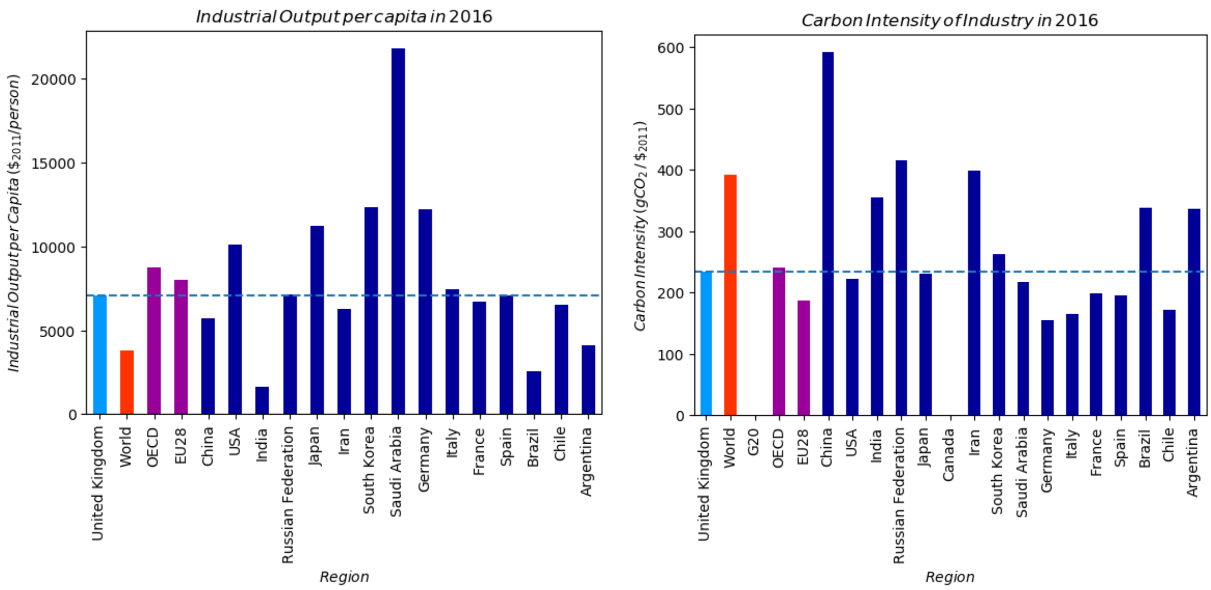

Figure 15 – Industrial value added and energy intensity of industrial value added, 2016

Notes – The industrial sector corresponds to ISIC divisions 10-45, and the services sector corresponds to ISIC divisions 50-99, using ISIC revision 3; GDP on Purchasing Power Parity basis; Data for G20 and Canada unavailable

Source - IEA (2018b), World Bank (n.d.)

Considering steel production, one of the most energy-intensive sectors, the UK has a relatively low output per person, at about half the world average and almost a quarter of the OECD as a whole. In addition, the UK has experienced one of the higher rates of reduction in steel production per person in recent years (Figure 16). This provides some evidence of a shift from energy-intensive to less energy-intensive (but higher value-added) industrial production in the UK over this period. This is a probable contributor to the industrial sector's relatively higher rate of decarbonisation compared to the transport and buildings sectors. It should be noted that steel production doesn't indicate whether the UK's use of steel reduced over this period. In fact over the period 2012-2017, the UK's per person "apparent steel consumption" (a measure of demand) actually increased, from 150 t/capita in 2012 to 163 t/capita in 2017 (World Steel Association, 2018).

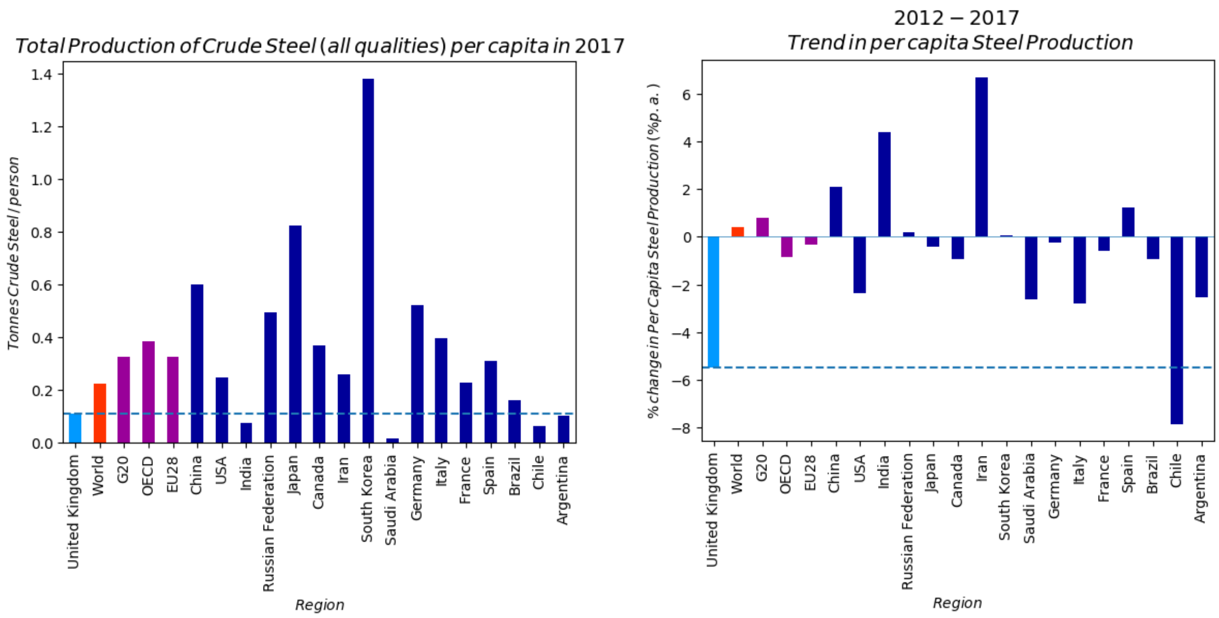

Figure 16 – Total crude steel production per person, 2017 and five year trend

Notes – Includes all qualities of cruse steel (carbon, stainless and other alloy)

Source - World Steel Association (2018)

2.3.3 Transport sector

Figure 9 showed that the UK has significantly higher per person transport sector CO_2 emissions than the world average, and about 20% higher than the EU, although 25% below the OECD as a whole. Furthermore, the UK's transport emissions per person have remained virtually flat over the last five years. As shown by Figure 17, the UK has commensurately higher energy intensity of transport per person than the world average, and about equal energy intensity of transport to the EU's. This means that the UK has a higher CO_2 emissions intensity of transport energy than the EU. As with transport CO_2 emissions per person, the UK has made little progress in reducing its energy intensity of transport, although this is also true of the EU, whilst most other countries and regions have actually seen a rise in transport energy intensity over the past five years.

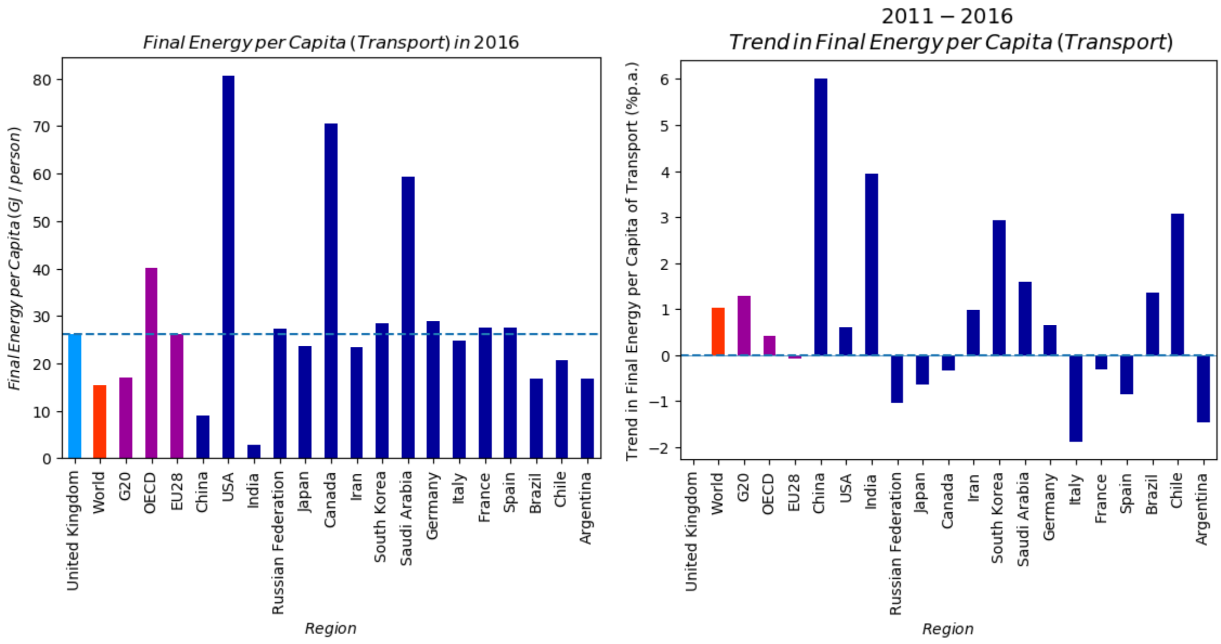

Figure 17 – Transport final energy per person, 2016 and five year trend

Source - IEA (2018a), World Bank (n.d.)

On specific technology penetration measures in the energy-demand sectors, the UK is also behind the leaders. For example, the share of plug-in electric vehicles (EVs) in new vehicle sales in the UK (<3%) is still relatively low compared to the leaders (Norway, 47%, Sweden, 7.5%).

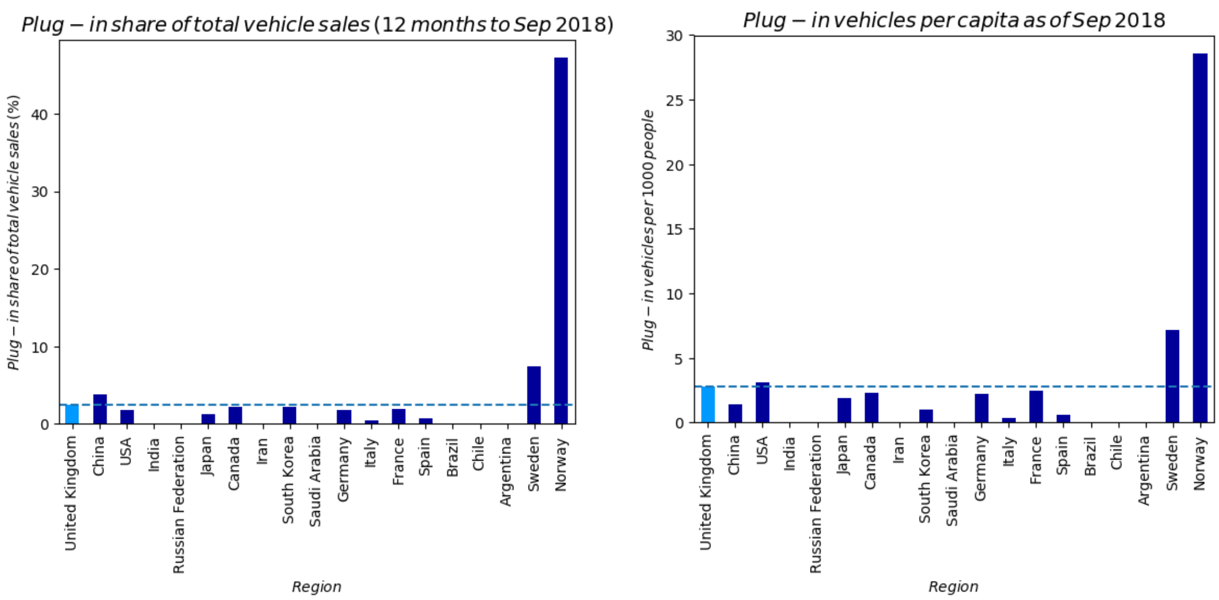

Figure 18 – Plug in vehicle share of sales (year to Sep 2018) and total on road (thousands, Sep 2018)

Source - EV-volumes (2018a, 2018b) as cited in Staffell et al. (2018)

2.3.4 Buildings sector

As with the transport sector, the UK has much higher buildings CO_2 emissions per person than the world average, as shown in Figure 9 (although as explained in Section 2.3, footnote 2, different climates can lead to different heating demands). The UK's per person emissions are slightly lower than the EU average, in spite of approximately equal final energy intensity (Figure 19). As with its transport sector, the UK has made relatively little progress in making its buildings more energy efficient in recent years, in line with the EU but slower than the OECD as a whole, as well as the USA.

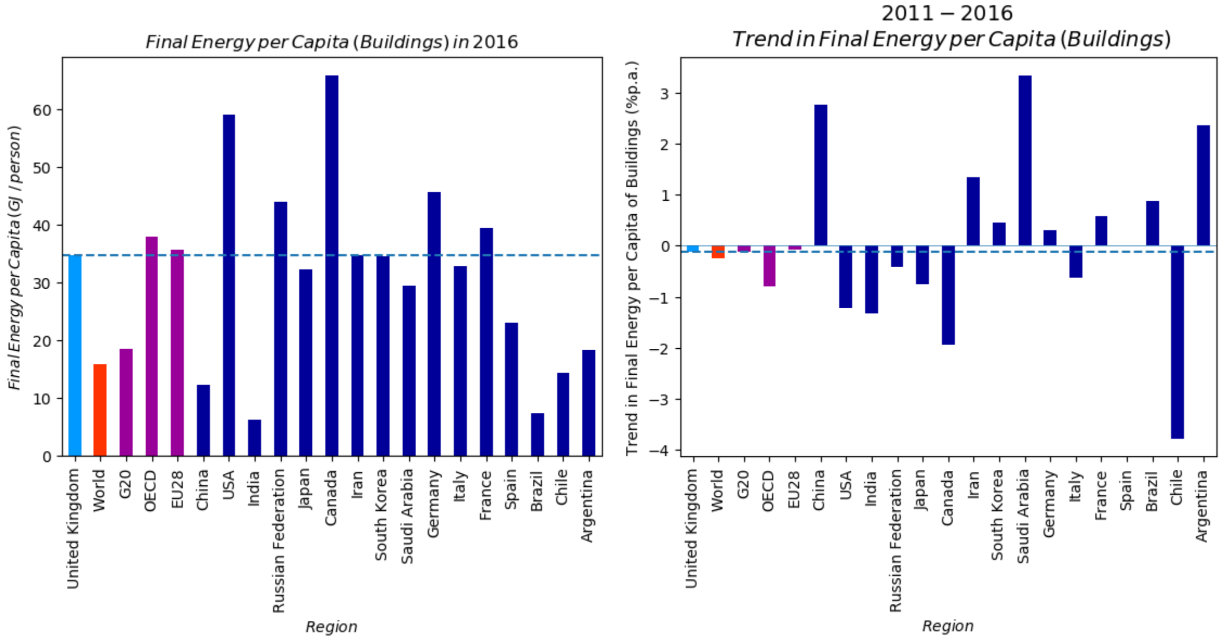

Figure 19 - Buildings final energy per person, 2016 and five year trend

Source - IEA (2018a), World Bank (n.d.)

2.4 Other greenhouse gas emissions

Energy Sector non-CO_2 emissions in the UK are relatively insignificant compared to CO_2 emissions (at 0.4tCO_2e/person, compared to the CO_2 emissions of 6.4tCO_2/person). The UK has a very small sink of CO_2 from the Land Use, Land Use Change and Forestry (LULUCF) sector, which in part reflects its relatively small land mass and relatively high population density, compared for example to highly forested and less population-dense countries such as Brazil. UK agricultural emissions (CH_4 and N_2O) are almost identical to the world average. However, the UK has in recent years reduced its agricultural emissions at a much lower rate than the global average, with UK methane emissions slightly rising, compared to a rapid fall globally.

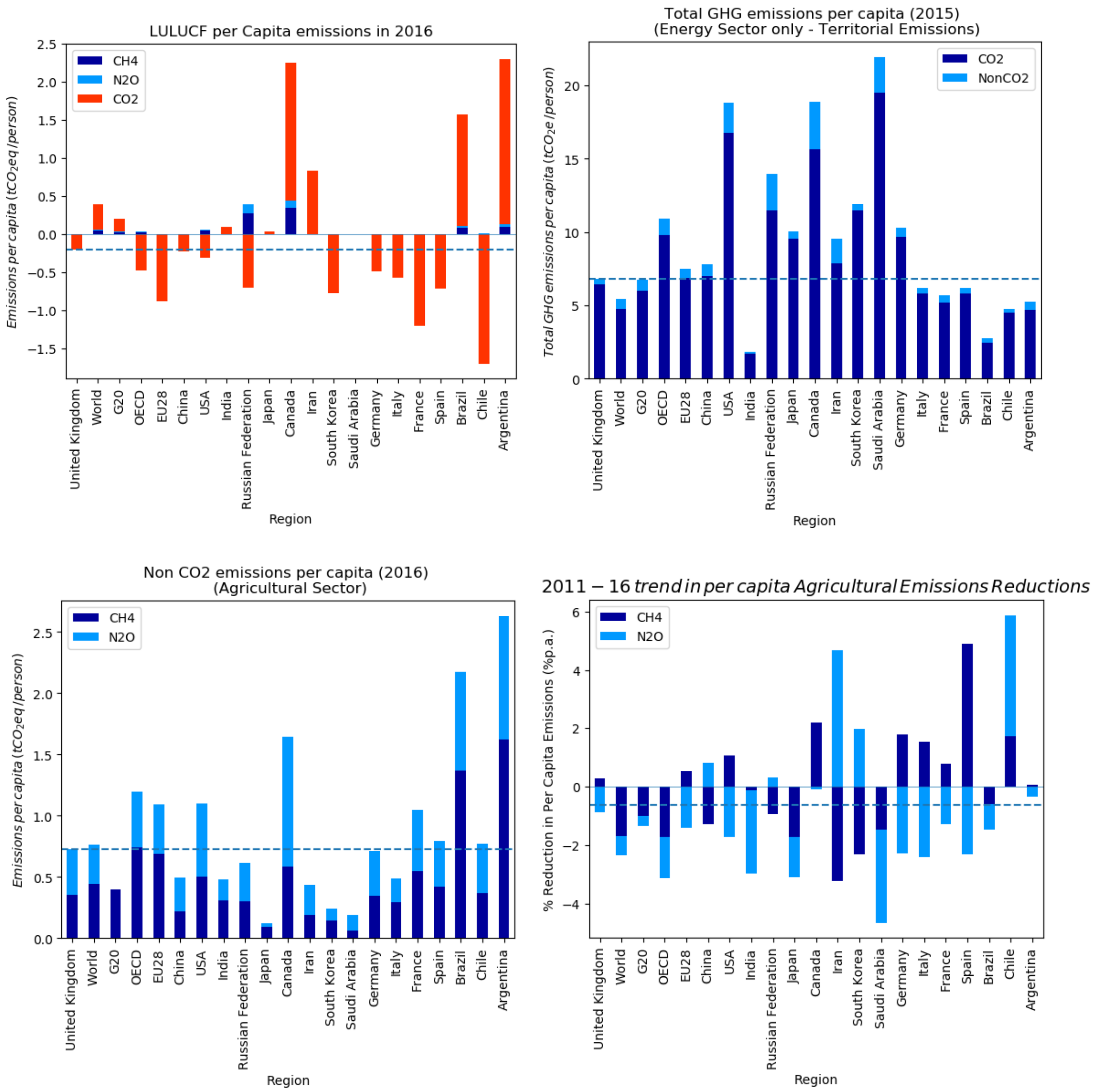

Figure 20 – Non-energy CO_2 and other non-CO_2 emissions per person

Notes – Land Use, Land Use Change and Forestry (LULUCF) emissions sourced from UN Food and Agriculture Organisation (FAO) – it should be noted that these emissions tend to be subject to high uncertainty and can vary greatly between different sources.

Source – FAO (n.d.), UNFCCC (n.d.)

So whilst the energy sector's CO_2 emissions, which form the bulk of UK total GHG emissions, have fallen rapidly in recent years, there has been a relative underperformance on non-CO_2 emissions (mainly from agriculture).

2.5 The UK's institutional framework to support emissions reductions

The UK has the potential to continue to lead in emissions reduction efforts in the coming decades, if it can continue to decarbonise its power sector, begin to decarbonise its thus far relatively resistant energy demand sectors (such as buildings and transport) and reduce emissions/sequester carbon in non-energy sectors.

A strong institutional framework is a prerequisite for undertaking ambitious emissions reductions, since it is necessary to formulate and implement long-term, stable and credible mitigation policies which can provide a sufficiently robust signal to business and civil society to undertake low-carbon investments and actions. The UK's institutional and framework, including the 2008 Climate Change Act and detailed multi-sectoral policy and regulatory framework, should place the UK in a good position to do this. For example, the UK scores relatively strongly on measures of governance and on the strength of its regulatory institutions (Figures 21 and 22). Regulatory quality (Figure 21) reflects "*perceptions of the ability of government to formulate and implement sound policies and regulations that permit and promote private sector development*" (World Governance Indicators, 2018). Examples of specific factors include fairness of taxation, competition and ease of starting a business.

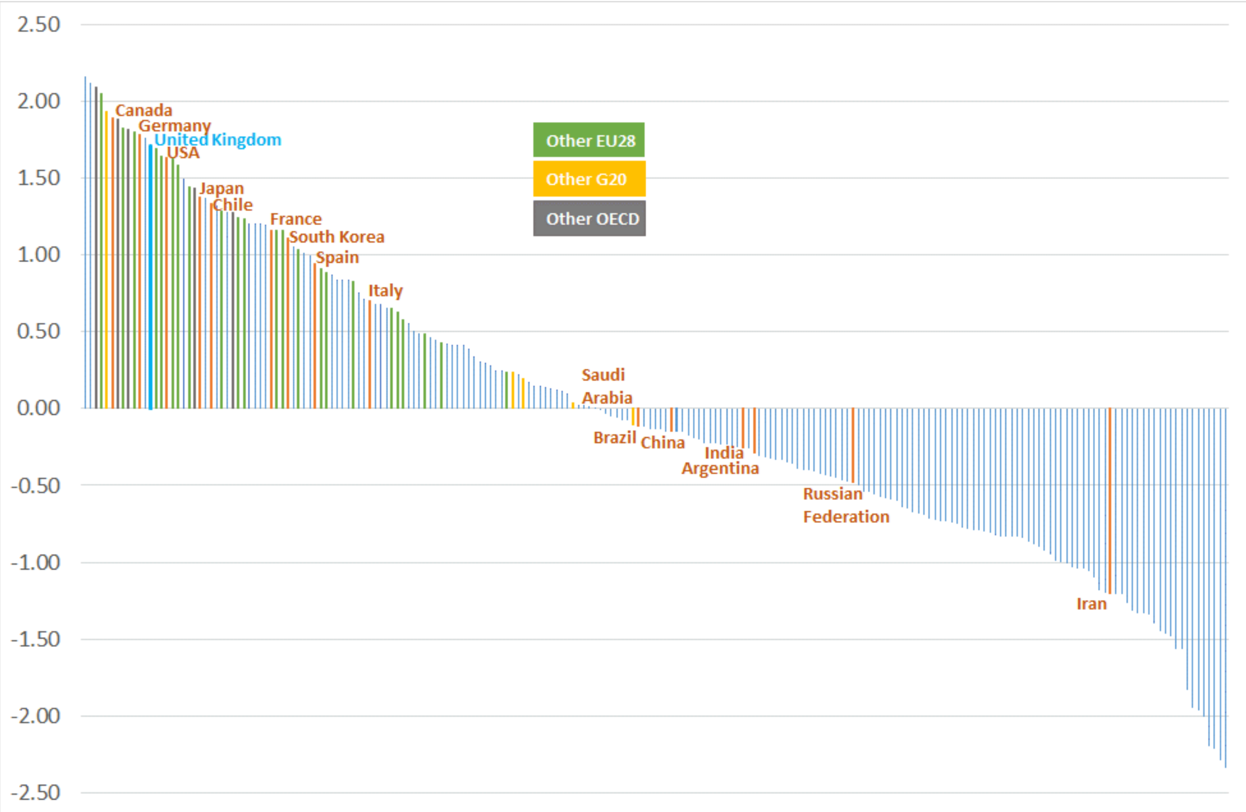

Figure 21 – Regulatory quality measure in 2017 (+2.5 = strong, - 2.5 = weak), 2017

Notes – "Other EU28" refers to the EU28 countries not including those shown individually (United Kingdom, Germany, France, Italy, Spain); "Other G20" refers to those G20 countries not shown individually nor as part of the EU28 group (i.e. Australia, Mexico, Saudi Arabia, South Africa, Turkey); "Other OECD" refers to those OECD countries not shown as part of EU28 nor as part of G20 (i.e. Iceland, Israel, New Zealand, Norway, Switzerland)

Source - World Governance Indicators (2018)

Government effectiveness (Figure 22) reflects *"perceptions of the quality of public services, the quality of the civil service and the degree of independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies"* (World Governance Indicators, 2018). Examples of specific factors include the degree of red tape, political stability, trust in government and degree of state failure to provide basic services.

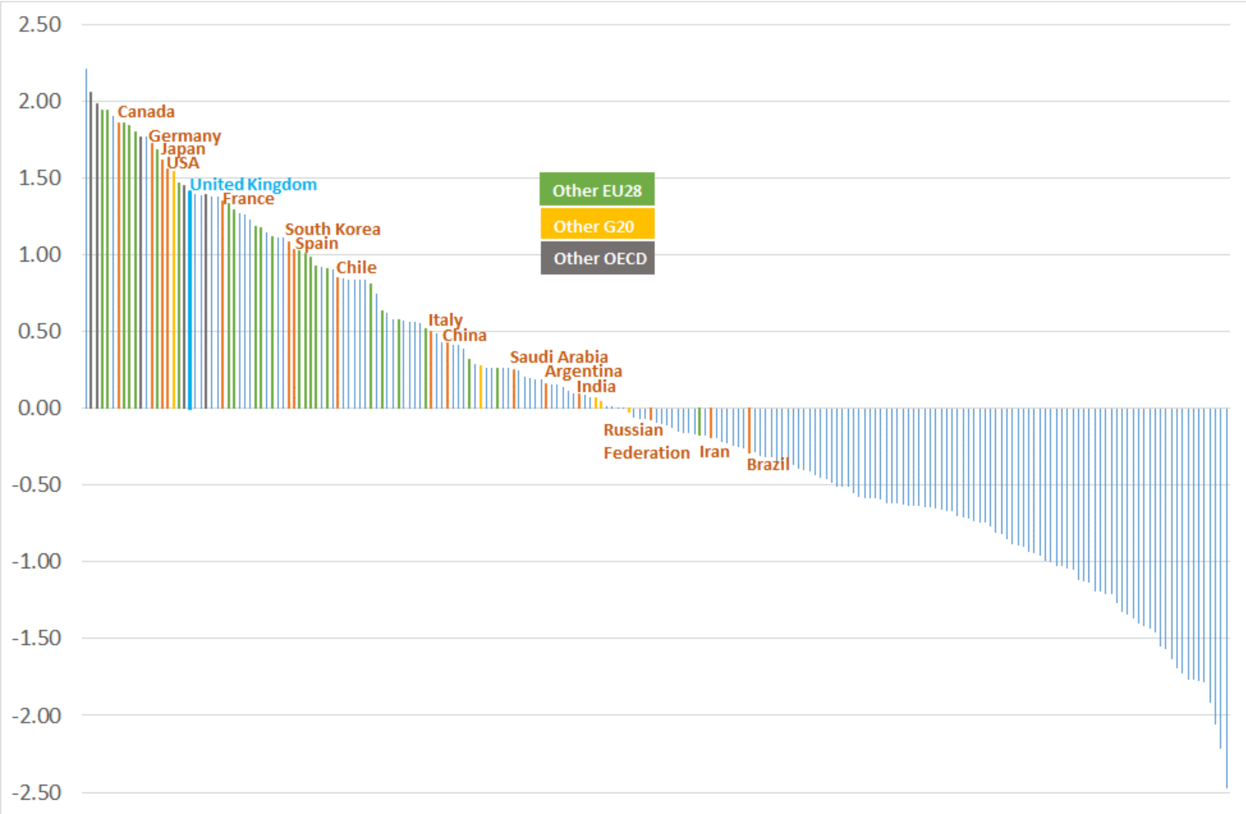

Figure 22 – Government effectiveness measure in 2017 (+2.5 = strong, - 2.5 = weak), 2017

Notes – "Other EU28" refers to the EU28 countries not including those shown individually (United Kingdom, Germany, France, Italy, Spain); "Other G20" refers to those G20 countries not shown individually nor as part of the EU28 group (i.e. Australia, Mexico, Saudi Arabia, South Africa, Turkey); "Other OECD" refers to those OECD countries not shown as part of EU28 nor as part of G20 (i.e. Iceland, Israel, New Zealand, Norway, Switzerland)

Source - World Governance Indicators (2018)

2.6 Summary of UK performance and future prospects to decarbonise

The UK has in recent years led the world in energy-sector CO_2 emissions reductions, which form the majority of its territorial greenhouse gas emissions. It has also been in the leading group of countries reducing their consumption-based emissions. It has achieved this without deindustrializing, maintaining a relatively stable industrial share of total economic output, although there is evidence that energy- and emissions-intensive industrial activities such as steel-making have declined in the UK, contributing to the overall decarbonisation of the UK's industrial sector.

The UK has performed worse than the global average in non-CO_2 emissions reductions from the agricultural sector, its next-most significant source of GHG emissions after energy-sector CO_2. In addition, the principal driver of the UK's energy-sector CO_2 emissions reductions has been rapid decarbonisation of the power sector, with transport and buildings emissions in particular remaining relatively stagnant compared to the EU as a whole.

Some countries have shown the potential to more rapidly decarbonise these sectors – for example Sweden and Norway's take-up of electric vehicles to decarbonise the transport sector. The UK compares favourably to most other countries in terms of its institutional regulatory and policy framework, so should be well placed to replicate other countries' success in decarbonising their demand (transport, buildings and agriculture) sectors, as well as further decarbonising its power sector through increasing its share of low-carbon power sources.

3 Modelled regional emissions reduction effort in stringent emissions reduction scenarios

3.1 Scenario overview

A large number of low-carbon pathways have been produced to analyse how different regions and the world as a whole might reduce their emissions over the coming decades, in stringent mitigation scenarios. These scenarios have been produced using Integrated Assessment Models (IAMs), which represent the world as a number of regions (generally between 10 and 20). In the majority of scenarios, the IAMs simulate how the world as a whole can meet prescribed climate targets, with emissions reductions occurring at different points in time in those regions where it is least costly to do so. This "cost-minimising" approach can therefore indicate how – in principle – emissions reduction effort is divided amongst regions in order to achieve a least cost solution to meeting a given climate target. It can therefore provide one set of evidence on how different regions could mitigate towards the Paris goal.

The IPCC-SR1.5 encompasses 78 scenarios which are consistent with limiting long-term temperature change to 1.5°C (with >50% likelihood), as well as 121 scenarios consistent with a 2°C warming limit (with >50% likelihood). For this analysis, we have selected a small subset of these scenarios to illustrate the emissions, land use and energy system transformation pathways in 1.5°C and 2°C scenarios. The scenario selection has the following features:

- We choose "middle of the road" socio-economic assumptions for population and economic growth and how these factors drive future energy, agricultural and land use demand. These are as described in the second shared socio-economic pathway (SSP2)[4]. It should be noted that there are other scenarios in the IPCC-SR1.5 database that have much higher and lower levels of future economic growth, population and energy demand;
- We choose scenarios which do not explicitly include regional differentiation of climate policy, which means they tend to see regions rapidly converging to a uniform global carbon price;
- For each of the Baseline, 1.5°C and 2°C scenario groupings, we select only one scenario from each integrated assessment model used to produce scenarios in each grouping, to avoid bias towards models from which many scenarios are represented in each grouping;
- For 1.5°C scenarios, we select only those which achieve this long-term goal with either no temperature overshoot, or a "low" overshoot, which the IPCC-SR1.5 describes as <0.1°C as assessed using the MAGICC simple climate model;
- For 2°C scenarios, we select only those scenarios which achieve a 2°C goal with >66% likelihood. The IPCC-SR1.5 places these in a specific category named "Lower 2C". We refer to these throughout this section as 'well-below' 2°C scenarios consistent with the main CCC advice report.
- For Baseline scenarios, we select from the IPCC-SR1.5 database a suitable baseline for each model whose results are used in the above two temperature groupings.

This results in 18 modelled scenarios being used for the analysis in the following sub-sections, as detailed in Table 1. For the IPCC-SR1.5 scenario database, each model reports outputs for 5 mutually exclusive regions[5]:

[4] Full details of the SSPs and their underlying storylines and assumptions are available in O,Neill et al. (2014)

[5] Full list of countries available at Huppmann et al. (2018): https://db1.ene.iiasa.ac.at/IPCCSR15DB/dsd?Action=htmlpage&page=about#regiondefs

1. Asia (including China, India, Indonesia, South Korea, other South East Asia and South Asian countries, EXCEPT Japan and Former Soviet countries and Australia and New Zealand);
2. Latin America (including Brazil, Argentina, Chile, Mexico, other South and Central American and Caribbean countries);
3. Middle East and Africa (including Saudi Arabia, Iran, Iraq, Israel, other Middle Eastern countries; North African countries, South Africa and other sub-Saharan African countries);
4. OECD90 (i.e. the OECD countries as at 1990, including USA, Canada, Japan, Australia, New Zealand) and the EU28 countries, combined;
5. Reforming economies (including Russian Federation, Ukraine, other Former Soviet countries).

Table 1: Models and scenarios used in each scenario grouping

Scenario grouping	Model	Scenario
Baseline	AIM/CGE 2.1	CD-LINKS_NPi
	IMAGE 3.0.1	CD-LINKS_NPi
	MESSAGEix-GLOBIOM 1.0	CD-LINKS_NPi
	POLES ADVANCE	EMF33_Baseline
	REMIND-MAgPIE 1.7-3.0	CD-LINKS_NPi
	WITCH-GLOBIOM 4.4	CD-LINKS_NPi
Well below 2°C	AIM/CGE 2.1	CD-LINKS_NPi2020_1000
	IMAGE 3.0.1	ADVANCE_2020_WB2C
	MESSAGEix-GLOBIOM 1.0	CD-LINKS_NPi2020_1000
	POLES ADVANCE	ADVANCE_2020_Med2C
	REMIND-MAgPIE 1.7-3.0	CD-LINKS_NPi2020_1000
	WITCH-GLOBIOM 3.1	CD-LINKS_NPi2020_1600
1.5°C	AIM/CGE 2.1	CD-LINKS_NPi2020_400
	IMAGE 3.0.1	IMA15-Def
	MESSAGE-GLOBIOM 1.0	ADVANCE_2020_1.5C-2100
	POLES ADVANCE	ADVANCE_2020_1.5C-2100
	REMIND-MAgPIE 1.7-3.0	SMP_1p5C_Def
	WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_400

Source - Huppmann et al. (2018)

The following sub-sections analyse the similarities and differences in emissions and energy system changes between these different regions, with a view to understanding how regional emissions reduction effort is differentiated. The analysis focuses on the median values across the modelled results, as designated by the filled diamond markers.

3.2 Regional CO_2 and greenhouse gas emissions

In the median of the selected 1.5°C scenarios, the world and each region reach a level of GHG emissions per person which is close to net-zero by 2050, as shown in Figure 20. By contrast there is fairly significant inter-regional variation in the level of GHG emissions per person in 2050 in the well below 2°C scenarios. Furthermore, in the well below 2°C scenarios, the average level of 2050 emissions per person in the relatively more developed OECD and EU countries is about 4tCO_2e/person, significantly higher than in the less developed countries which dominate the Asia, Latin America and Middle East and Africa regional groupings.

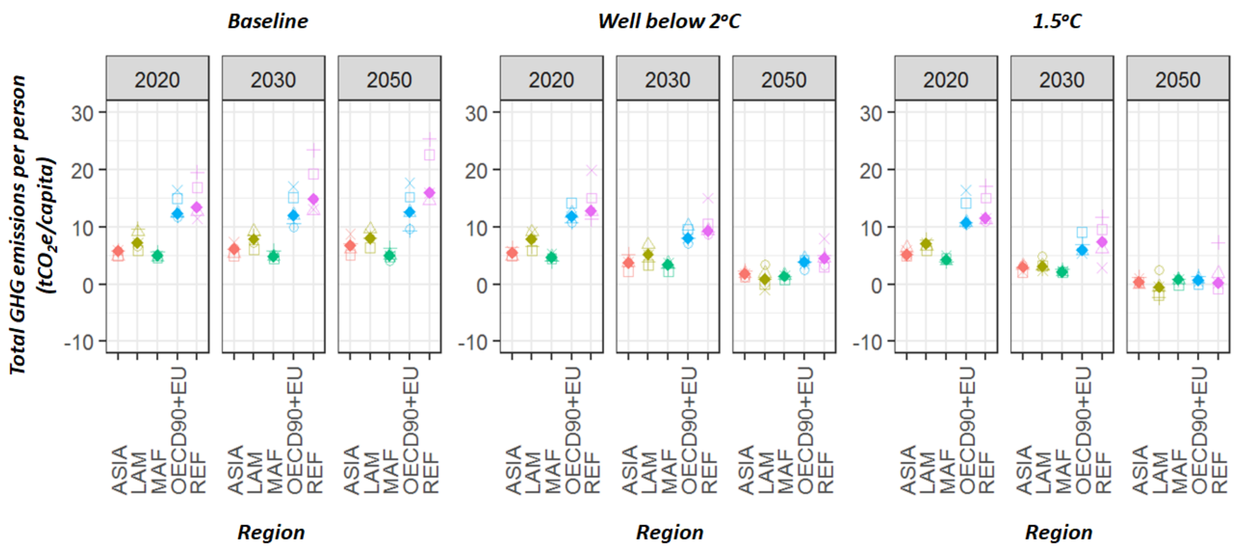

Figure 23 – Regional per capita GHG emissions

Notes – Diamond markers denote median values, with all model results shown in faded markers.

Source – Huppmann et al. (2018)

Considering total CO_2 emissions (including the energy and LULUCF sectors), all regions' per person emissions are at or below net zero CO_2 by 2050 in the 1.5°C scenarios. The Latin American region is the most decarbonised by 2050 in these 1.5°C scenarios, at just over -2tCO_2/person, as shown in Figure 24. The OECD+EU region experiences an almost 6% per year average annual reduction in CO_2 emissions per person over the decade 2020-2030 in the median of these 1.5°C scenarios, compared to the UK's 5% per year rate of reduction of (energy-sector) CO_2 emissions reductions over the period 2012-2017, as shown in Figure 4 in Section 2. So even for the UK, which has significantly outperformed other countries on a territorial emissions reduction basis, this would represent an acceleration of mitigation effort. Between 2030 and 2050, the OECD+EU region's average (linear) rate of emissions reduction slows slightly, to about 5% per year.

In the well below 2°C scenarios, as in the case of total GHG emissions, total CO_2 emissions per person in the OECD+EU region are significantly higher than in some other regions by 2050, especially Latin America, which has slightly net negative emissions by 2050. The median rate of OECD+EU CO_2 emissions reductions in the 2020-2030 period is on average 3% per year, less than the rate of reduction than the UK has achieved over the last 5 years.

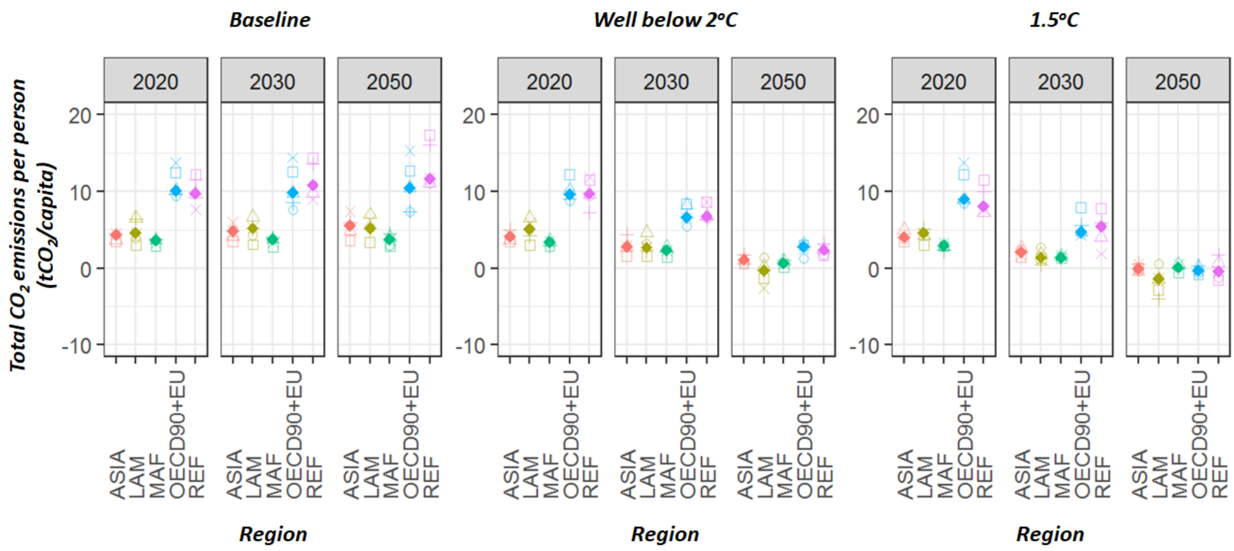

Figure 24 – Regional total CO_2 emissions per person

Notes – Total CO_2 emissions includes from fossil fuel combustion, industrial processes and agriculture, forestry and land use (AFOLU); Diamond markers denote median values, with all model results shown in faded markers.

Source – Huppmann et al. (2018)

The strikingly different behavior of the Latin American region is in large part driven by assumed emissions sinks from its land use sector, as shown in Figure 25. In fact most scenarios show that this sector has shifted from a significant net source in 2020 to a significant net sink by as early as 2030 in the 1.5°C scenarios.

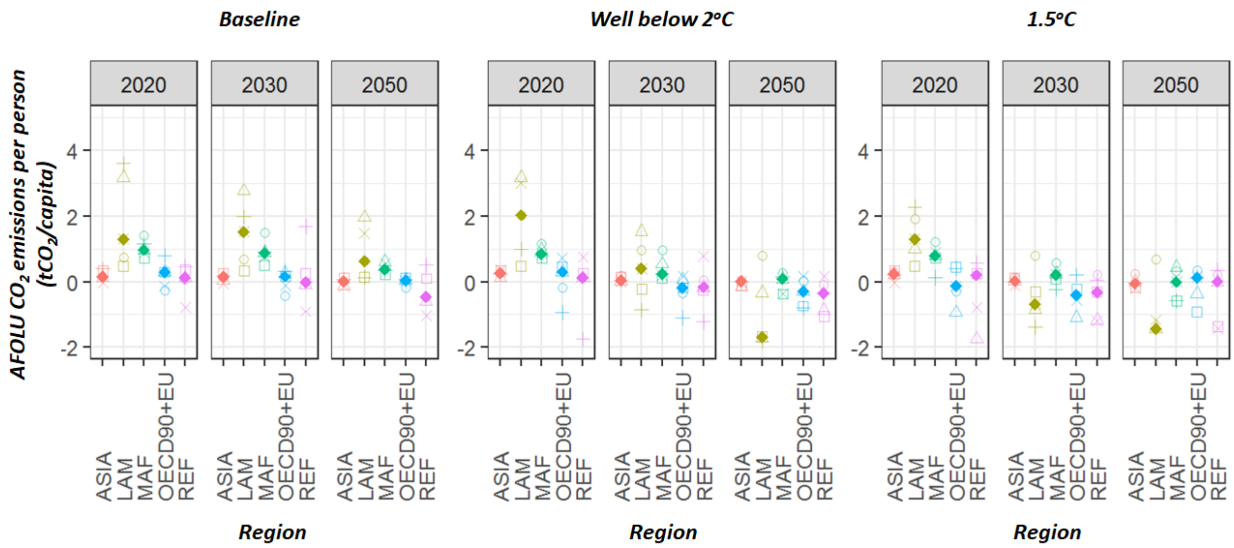

Figure 25 – Regional per person AFOLU CO_2 emissions

Notes – Diamond markers denote median values, with all model results shown in faded markers.

Source – Huppmann et al. (2018)

3.3 Energy system transformations

Considering specific energy-system metrics, final energy intensity of GDP shows significant current variation between regions, but converges to a much narrower range by 2050 in the well below 2°C scenarios and an even narrower range in 1.5°C scenarios, indicating that relatively less expensive energy efficiency and energy demand reduction measures are taken up everywhere (Figure 26) as the temperature target is lowered.

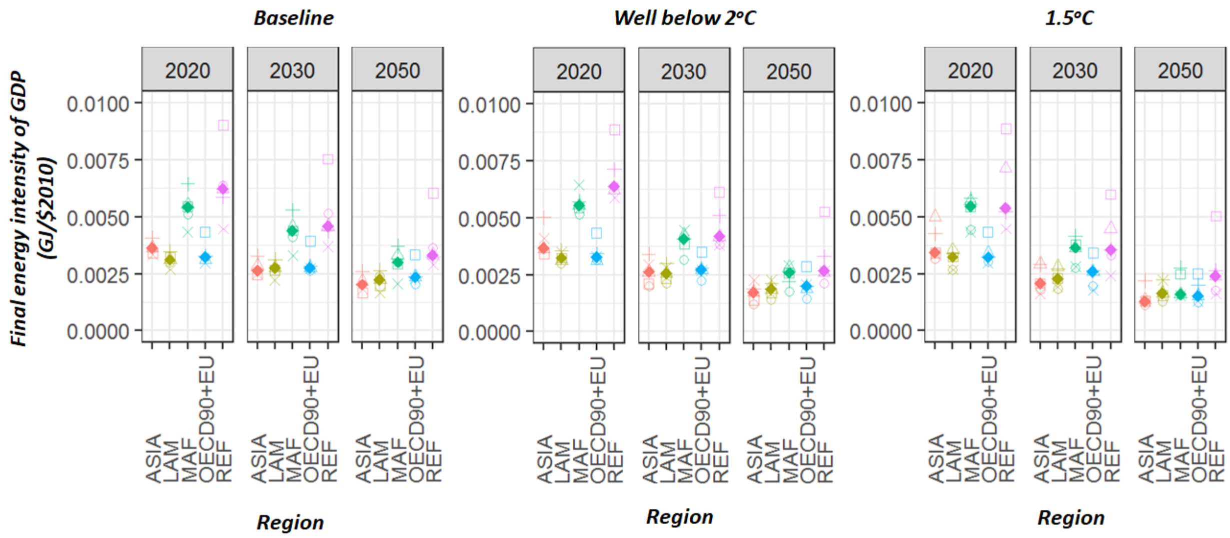

Figure 26 – Regional final energy intensity of GDP

Notes - Diamond markers denote median values, with all model results shown in faded markers.

Source – Huppmann et al. (2018)

To a large extent this convergence of energy intensity of GDP also happens in the baselines, with a relatively small increase in speed of reductions in the ambitious climate policy scenarios. This implies that the main emissions reductions come from an accelerated reduction in the carbon intensity of emissions per unit of energy consumed, as for example shown in Figure 27 for industrial sector final energy. As discussed in Section 2.2, the UK's recent experience in leading on emissions intensity of energy is a useful indication of its ability to lead on emissions reductions in the future.

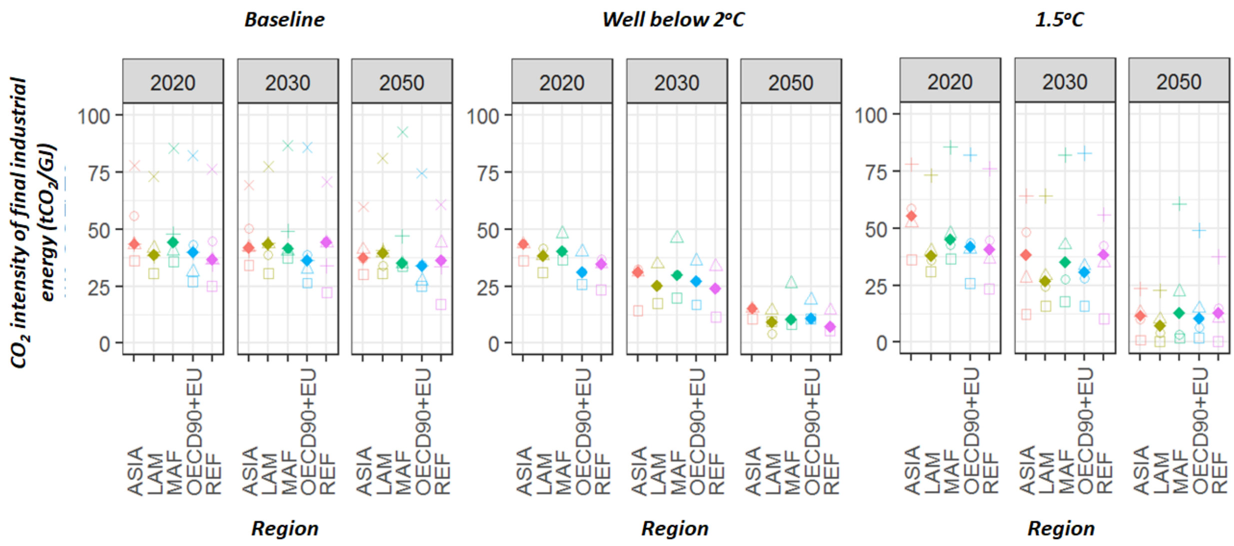

Figure 27 – Emissions intensity of final energy in industrial sector

Notes – Limited model results available for well below 2°C scenarios, so cannot be directly compared to baseline / 1.5°C scenarios

Source – Huppmann et al. (2018)

In addition, the share of low-carbon technologies increases markedly in all regions in the 1.5°C scenarios and well below 2°C scenarios. For example whereas the OECD+EU and Latin America regions see a higher share of low-carbon electricity generation in the baseline scenarios, in the mitigation scenarios this share is very much in line with the world average by 2050. Many countries in diverse geographical locations, including Denmark (where wind power accounts for about half of electricity generation), Canada (about two thirds hydro), Brazil (about three quarters hydro) and France (about three quarters nuclear) demonstrate the real-world feasibility of achieving the 2050 shares shown, capitalizing on their individual renewable resources and other low-carbon technology choices.

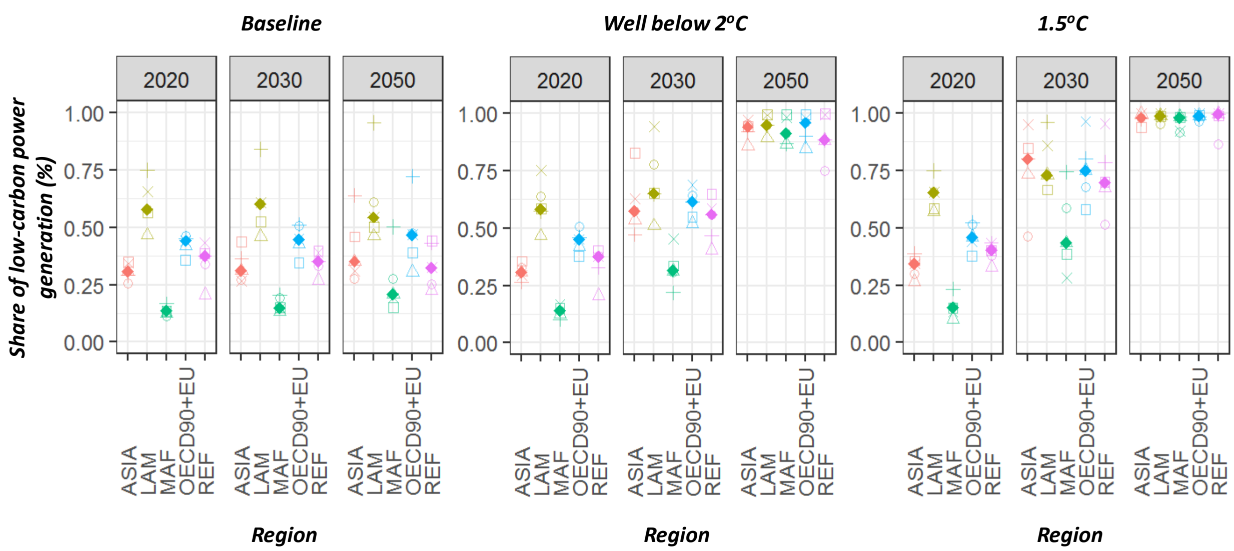

Figure 28 – Low-carbon sources share of total electricity generation

Notes – Low-carbon sources include renewables, nuclear and carbon capture and storage (CCS)

Source – Huppmann et al. (2018)

In contrast to low-carbon electricity generation, unabated fossil fuel generation (i.e. oil, gas and coal without carbon capture and storage) play virtually no role in each region's electricity system by 2050, in either the 1.5°C or well below 2°C scenarios, as shown in Figure 29. Oil-fired generation disappears from all regions by 2030 even the baseline scenarios, whilst coal (which persists in Asia in the baselines) virtually disappears in the mitigation scenarios by 2050. Gas-fired electricity generation (the least carbon-intensive fossil source) plays a significant role across most regions by 2030, but mostly disappears by 2050, with the exception of the OECD+EU region in the well below 2°C scenarios, where it makes up just under 10% of total generation in the median case.

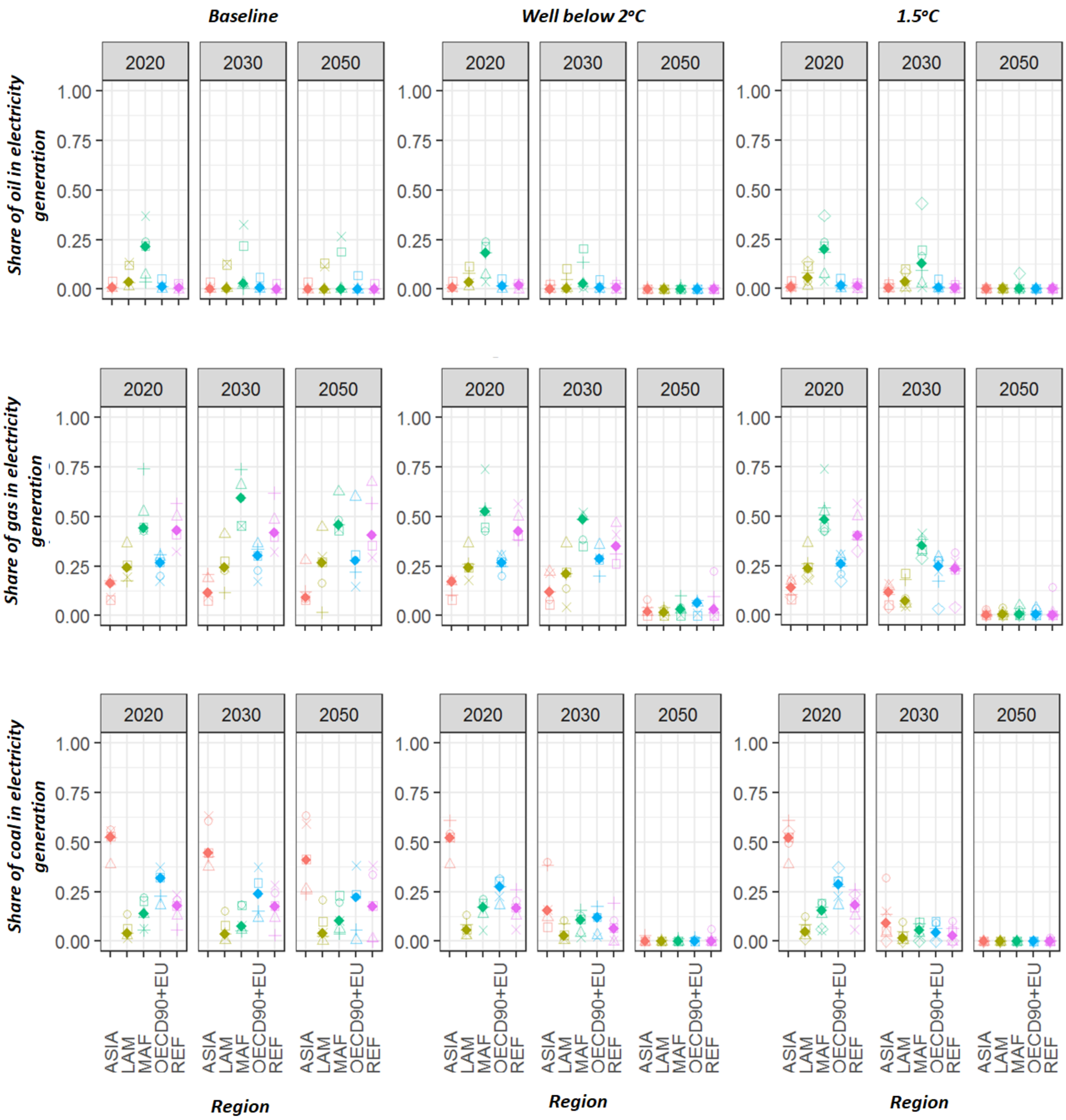

Figure 29 – Shares of unabated fossil fuels in electricity generation

Notes – Here unabated means generation from fossil plants with carbon capture and storage (CCS) is not included

Source – Huppmann et al. (2018)

This increasing share of low-carbon sources in electricity generation, at the expense of unabated fossil fuel generation, contributes to a rapid reduction in the carbon intensity of electricity generation in all regions, to approximately net zero by 2050 in the mitigation scenarios (Figure 30).

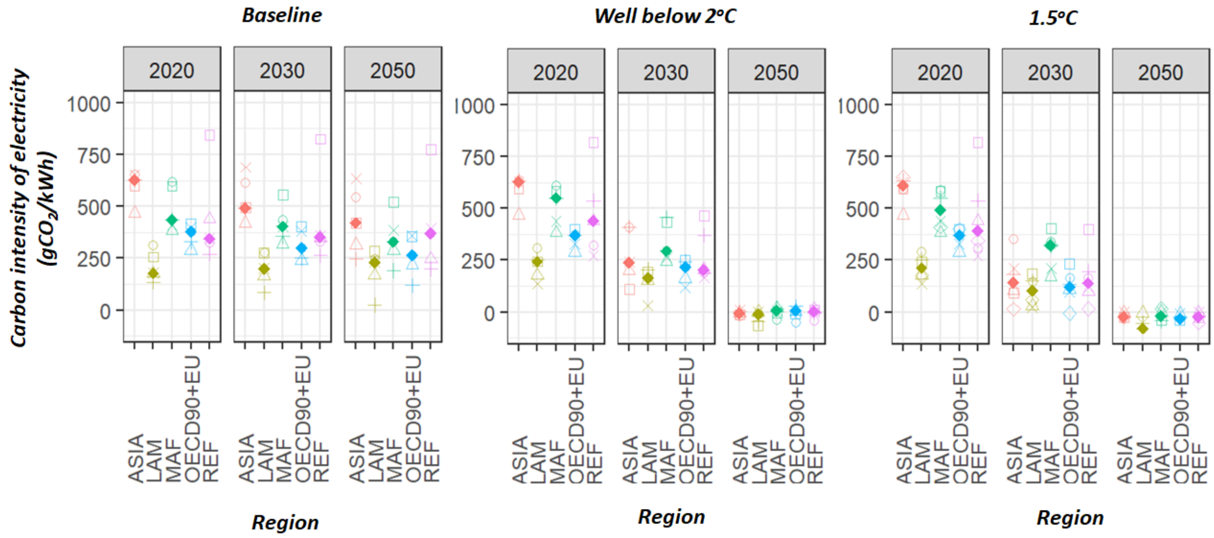

Figure 30 – Carbon intensity of electricity generation

Source – Huppmann et al. (2018)

In order to produce the regional scenario results reported in Sections 3.2 and 3.3, most modelling teams take into account inter-regional differences in the availability of key mitigation resources such as land, forestry, and renewables resources such as hydro, wind and solar potential resulting from local geography and weather conditions. The model teams also make assumptions on inter-regional differences in the costs of mitigation options, such as the costs of installing low-carbon technologies such as wind turbines and solar panels. Regional costs often reflect regional differences in economic output per person and wage rates, which tends to result in low-carbon technologies being cheaper to deploy in less developed economies compared to developed economies (see for example Krey et al., 2019, which shows a number of IAMs reporting lower capital costs of power sector technologies in Brazil, China and India compared to EU, USA and Japan).

This assumption of relatively more expensive mitigation options in developed economies, combined with their much higher current levels of emissions per person, explains why many of the modelled pathways show less developed economies reaching zero net emissions earlier. In the case of the more stringent 1.5°C scenarios, all countries tend to reach zero net CO_2 emissions around 2050, owing to the need to achieve this level of emissions globally by this time and the fact that (model simulated) maximum feasible mitigation rates are being encountered in many regions with these very tight carbon budgets (for example see Luderer et al., 2018 and Rogelj et al., 2018 which both highlight the degree of challenge in meeting the 1.5°C target).

It is important to note that these scenarios provide only a hypothetical picture of where emissions reductions would occur if driven by cost considerations only. They do not take into account other dimensions of feasibility as discussed in the IPCC-SR1.5, including institutional, economic and technological feasibility or broader considerations of 'fairness' that are enshrined in the Paris Agreement. Whilst mitigation options may well be cheaper in many less developed economies, lack of institutional capacity to introduce strong, binding mitigation policies, lack of access to capital to fund such mitigation, and lack of access to low-carbon technologies could be significant barriers to mitigation.

Furthermore, many less developed countries have growing middle classes with a desire, and the means, to increase their energy and material consumption, following socio-economic development patterns of the developed economies. This could severely limit the socio-cultural feasibility of achieving many of the behavioural changes associated with the deep transformation required in 1.5°C or well below 2°C scenarios.

Recent analysis (Van den Berg et al., 2019) has found that the share of the remaining global carbon budget allocated to the more developed countries and regions (USA, European Union, Japan and Russia) in cost-minimising 1.5°C and well below 2°C scenarios is significantly higher than in many equity-based effort-sharing regimes, such as equal per capita emissions and ability to pay regimes. At the same time, the carbon budgets of less developed countries (including China, India and Brazil) are lower in cost-minimising scenarios than they would be in these effort-sharing regimes. Indeed Brazil received a negative carbon budget allocation over the period 2011-2010, owing to its assumed cheaper emissions removal potential. This is in part reflected in the Latin American region reaching net negative emissions earlier than other regions in most modelled 1.5°C scenarios, as shown in Figure 24 above.

Additional analysis (Hof et al., 2017) suggests that, under a cost-optimal effort-share of emissions reductions, less developed countries and regions would experience higher mitigation costs, as a share of their GDP, in 2030, as shown in Figure 31, even though mitigation costs might be less in absolute terms. These analyses suggest the cost-minimising approach does not adequately reflect many equity, fairness or capability criteria, if the cost of achieving these regional reductions was exclusively domestic and not supplied (in part) through large transfers under international carbon markets.

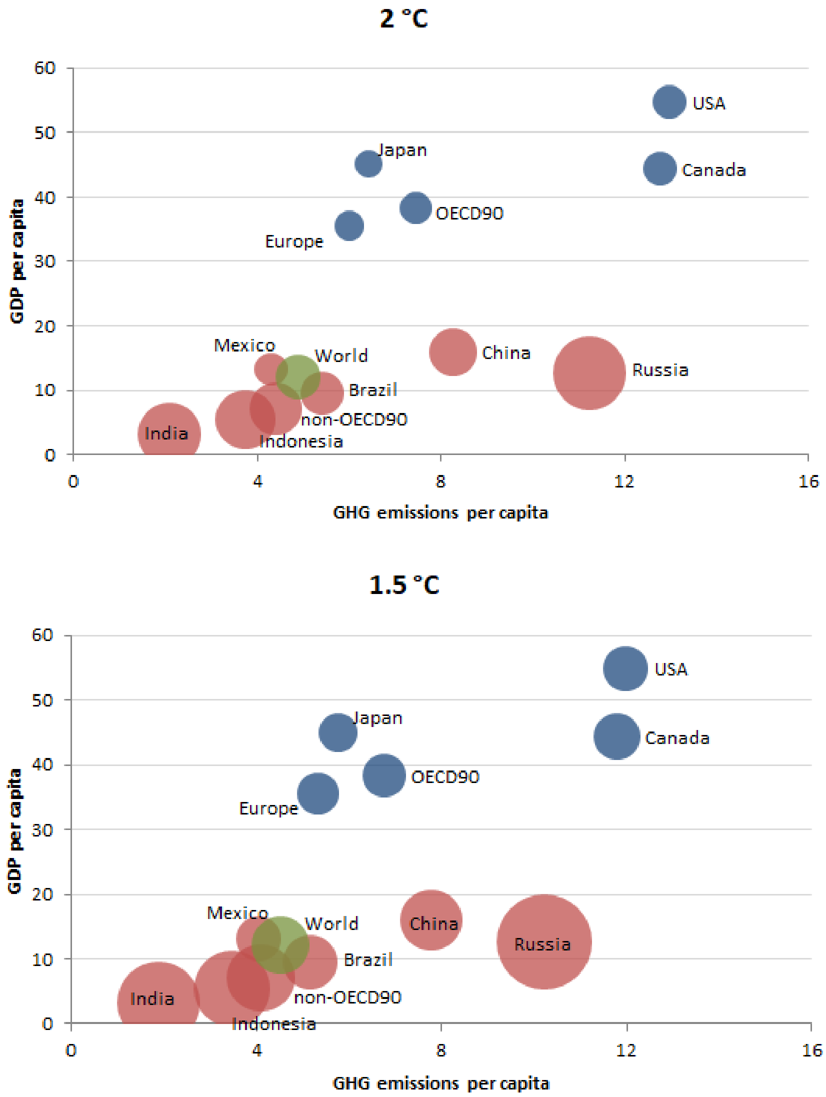

Figure 31 – 2030 mitigation cost as share of GDP for different countries and regions, in 1.5°C and 2°C scenarios

Notes – Circle size depicts annual mitigation cost in 2030. For reference, Japan = 0.19% (2°C) and 0.35% (1.5°C)

Source – Reproduced (with permission) from Hof et al. (2017)

3.4 Summary of modelled analysis of regional effort

The scenarios analysed in this section indicate that there is relatively less mitigation effort in developing regions in well below 2°C scenarios compared to developed regions, whereas in 1.5°C scenarios there is a convergence amongst all regions to highly decarbonised, approximately net zero CO_2, economies, by 2050. These regional mitigation results from cost-minimising modelled scenarios, as presented in this Section, must be treated with caution if interpreted directly as a desirable real-world regional split of the global mitigation effort, since they only tend to take into account theoretical mitigation cost differences between regions. However, in providing a picture of where emissions reductions might be achieved in a globally least costly manner, they can provide a useful guide for how developed countries could assist less developed countries to ensure the least cost emissions reductions are achieved regardless of where these take place, for example through the use of functioning international carbon markets.

4 Regional pledges and assessments of emissions reduction

In practice, emissions reductions are more likely to progress rapidly where there is a robust institutional, regulatory and technology innovation and development base, as well as where there is available finance for investing in low-carbon technologies, energy efficiency and other emissions reduction measures. It is therefore instructive to look at the current long-term decarbonisation plans of different regions, as well as national-level modelled pathways produced within different regions. These assessments provide evidence regarding the extent to which different regions judge themselves capable of rapid emissions reductions, which helps indicate where the share of global emissions reduction effort could fall in more stringent scenarios.

Different regions' current emissions reduction goals to 2030, as pledged at the Paris conference in 2015 (and known as the nationally determined contributions, or NDCs) reveal regional differences in emissions reduction ambitions (Figure 32). Looking to those regions that have expressed goals to 2050, the EU is more ambitious than either Japan or the USA, in terms of targeted CO_2 emissions per person by 2050.

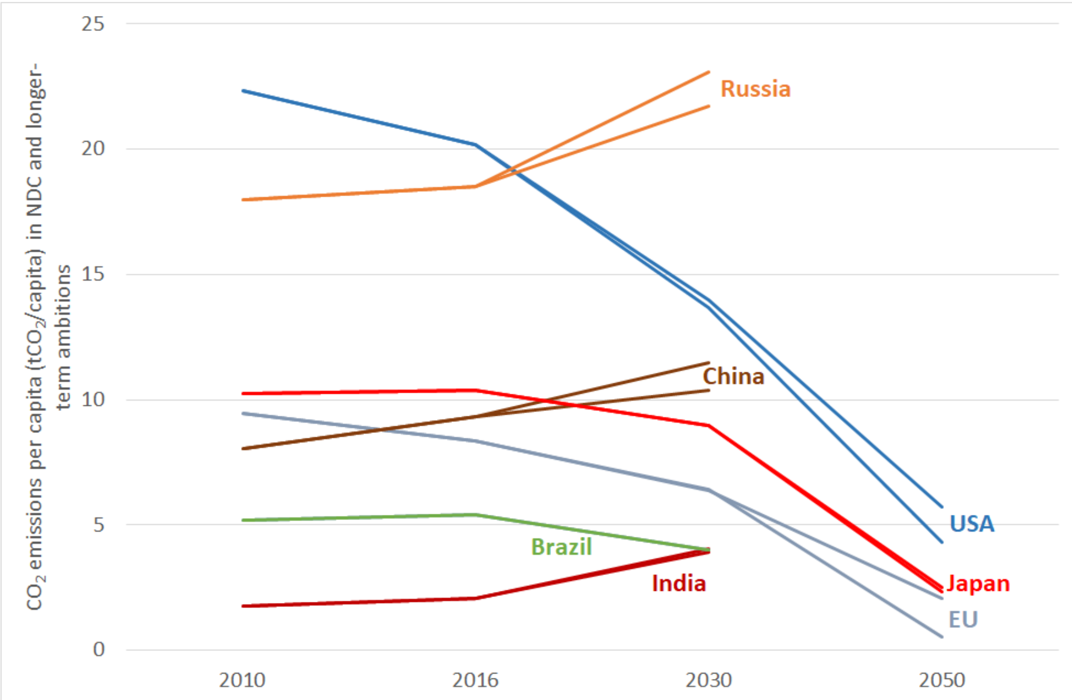

Figure 32 – Historic 2010-2016, projected 2030 NDC pledges and longer-term emissions goals, indexed to 2010

Source - Climate Action Tracker (2018). Copyright © 2018 by Climate Analytics, Ecofys, a Navigant company, and NewClimate Institute

Country-level analysis by national modelling teams under the IDDRI/SDSN Deep Decarbonization Pathways Project (2015) reveals the different scales of ambition to achieve deep decarbonisation by 2050[6]. Most countries achieve either a significant reduction in CO_2 emissions per person by 2050, or (in the case of India and Brazil) retain a relatively low emissions per person level throughout the

[6] It should be noted that the Deep Decarbonization Pathways Project scenarios were undertaken before the Paris Agreement, and aimed for emissions reductions consistent with limiting global warming to 2°C.

period to 2050. It is important to note that this is only a subset of all countries, focusing on major current emitters, and that other developing countries (e.g. sub-Saharan African countries) which haven't been analysed here could have very different emissions profiles to 2050.

A striking exception is China, which has a 2-4 times higher per person emissions level by 2050, compared to the other countries[7].

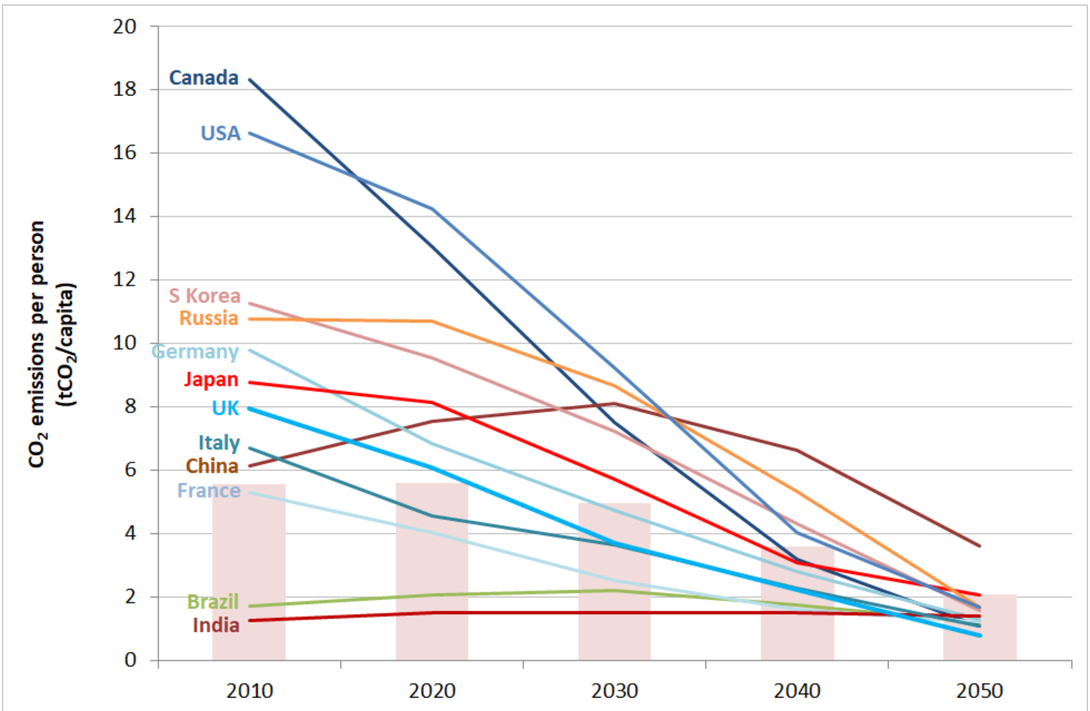

Figure 33 – Energy sector CO_2 emissions per person in Deep Decarbonization Pathways Project most ambitious scenarios

Notes – Energy sector covers fossil fuel combustion for energy use, as well as industrial process emissions

Source – Reproduced (with permission) from Deep Decarbonization Pathways Project (2015)

Table 2 summarises the influencers (drivers and barriers) to achieving deep decarbonisation for those countries in Figure 33 which have the highest (arbitrarily chosen as greater than $1.5tCO_2$ / person) level of per person emissions by 2050 (China, Japan, Russia, South Korea, USA). In most cases (particularly China and Russia) a key challenge to achieving deep decarbonisation is these countries' high dependence on fossil fuels.

[7] When measured on a territorial emissions basis as shown, rather than on a consumption emissions basis

Table 2: Factors that influence decarbonisation in countries with highest CO_2 per person by 2050

Country	Influencers of ability for Deep Decarbonisation
China	**Socio-economic** Economic growth dominates the political agenda. Economic reliance on emissions-intensive manufactured goods Rapid industrialisation and urbanisation **Resources** Many provinces still highly reliant on extraction of coal. China has plentiful solar and wind resources, as well as hydro although that has already been highly exploited. **Technology and infrastructure** Potential for development of non-fossil fuel based energy infrastructure **Governance** Climate change prominent in government planning, and development of low-carbon goods is seen as a driver of future economic growth.
Russia	**Socio-economic** Gradually declining population Economic growth is fossil fuel dependent **Resources** Large coal, oil, gas reserves, although cheaper reserves exhausted in 10-20 years Significant renewable energy resources, including bioenergy, hydro, geothermal and tidal Leader in nuclear power technology Forests are losing their net sinking abilities owing to increasing share of over-matured forest, expansion of forest fires and diseases. **Technology and infrastructure** Existing infrastructure fossil fuel orientated Large reliance on natural gas to transport gas and oil in pipelines Aging infrastructure in need of replacement and modernisation **Governance** Lack of focus on climate change compared to other economic expansion goals, lobbying from fossil fuel owners against a transition
Japan	**Socio-economic** Industrial manufacturing sector already highly energy efficient – limited further opportunities. **Resources** High fossil fuel import dependency Uncertain future role for nuclear power Relatively low land area available for renewables **Technology and infrastructure** Requirement to significantly improve infrastructure for integrating variable renewables. **Governance** Primacy of energy security in energy policy.
South Korea	**Socio-economic** Export-led growth dependent on energy-intensive heavy industries, already relatively energy-efficient, so with limited opportunities for further efficiency **Resources** Lack of CCS storage capacity

	Public acceptability limits nuclear potential Relatively low endowment of renewables resources **Technology and infrastructure** Green growth strategy identifies green industries as an engine for economic growth **Governance** Existence of green growth strategy but could be better aligned with domestic decarbonisation. Electricity sector regulation and pricing framework encourages over-consumption and lack of investment in renewables and energy efficiency. Lack of long-term vision and planning for national infrastructure investment.
USA	**Socio-economic** Gradual population growth (311 million in 2010, to 440 million in 2050), **Resources** High wind and solar resources, as well as nuclear. Sustainability limits applied to hydro power and biomass resources **Technology and infrastructure** Modelling uses conservative assumptions on technology availability and costs Modelling assumes infrastructure inertia: Longer lived infrastructure and energy assets (heavy duty vehicles, industrial boilers, electricity generation plants) will only be replaced once by 2050, so careful decisions need to be made now **Governance** Analysis recommends policy addresses electricity decarbonisation through the clean power plan, energy efficiency and electrification or other low-carbon fuels in transport and buildings, and decarbonisation of liquid fuels for industry and heavy transport.

Source – Deep Decarbonisation Pathways Project Country Reports and Additional Material, available at: http://deepdecarbonisation.org/

This analysis suggests that certain countries and regions (including the EU and UK), could feasibly reach very low (<1.5tCO_2 per person) emissions by 2050, whereas other regions (including China, Japan and Russia) might be less likely to do so, on the strength of their current ambitions, as well as a number of challenges, including critically their reliance on fossil fuels.

5 Summary

The analysis presented in this report provides a range of evidence on the potential ability of the UK to be a global leader in emissions reductions efforts to meet the Paris Agreement goals:

- The UK has demonstrated world-leading emissions reductions in recent years, driven by power sector decarbonisation;
- Decarbonisation in other sectors in the UK (especially transport, buildings and agriculture) has been much less impressive;
- The UK's strong institutional framework around climate change policy and policy/regulation more generally suggests it can emulate leaders in decarbonising these sectors;
- Modelled analysis of cost-optimal global low-carbon pathways suggests that in well below 2°C scenarios, more developed countries in the OECD and EU (i.e. including the UK) would have higher per person emissions by 2050 compared to less developed regions, owing to the latter regions' access to cheaper mitigation options;
- This modelled analysis also suggests that in1.5°C scenarios, all regions would achieve approximately net zero average CO_2 emissions by 2050;
- However, such modelled cost-optimal pathways tend not to account for a number of real-world differences between regions, including institutional capacity and access to finance, which could significantly hamper less developed regions' ability to mitigate as rapidly as more developed regions;
- Current country Paris pledges and longer-term ambitions, as well as national level modelling, suggest that the UK and EU can feasibly meet very low per person emissions levels by 2050, whereas some other regions might face greater challenges in doing so.

In summary, there is good evidence to suggest the UK can be part of a leading group of countries in mitigating towards Paris-consistent climate goals. However, a number of further considerations must be taken into account, including detailed sectoral analysis of UK mitigation potential, in particular around the energy demand sectors which have so far lagged both the UK's power sector, as well as the performance of international leaders in these sectors.

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