G20 low carbon competitiveness

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Preface from Lord Nicholas Stern

Chairman, Grantham Research Institute on Climate Change and the Environment, LSE

Head of the Stern Review on the Economics of Climate Change

This report on low carbon competitiveness comes at a critical time in the international negotiations on climate change. Over the next few months countries have the opportunity to adopt credible policies to reduce emissions and to prosper in a low carbon world. Moreover, the global economic recovery presents an ideal opportunity for countries to shift towards low carbon growth. Countries which don't seize this opportunity will undermine their future competitiveness and prosperity. The report by Vivid Economics provides an important picture of the competitiveness of the G20 countries. This type of analysis will be a welcome input into negotiations over the coming months.

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Executive Summary

A concerted global effort to reduce greenhouse gas (GHG) emissions will be required if a global average temperature rise of more than two degrees Celsius is to be avoided. Fundamental changes in both the global economy and the economy of each individual country will be necessary to achieve this goal. How each nation adapts to a carbon constrained world will, to a large extent, determine its future economic competitiveness and ability to create prosperity for its residents.

This report assesses the **low carbon competitiveness** of the nineteen G20 countries.[1] Traditional measurements of competitiveness fail to assess the consequences of how countries adapt to the opportunities and costs of moving to a carbon constrained world. This report seeks to fill this gap by providing a comparative, data-driven analysis of the progress countries are making to carry out this transition now and over time.

The G20 countries account for 76 per cent of world GDP and 69 per cent of total greenhouse gas emissions.[2] The G20 is therefore an important group in addressing climate change. Plans to unlock public and private sector financing for low carbon solutions are on the agenda at the upcoming G20 summit in Pittsburgh, USA in September 2009; therefore this meeting may play a crucial role in the lead up to the United Nations Climate Change Conference in Copenhagen in December 2009.

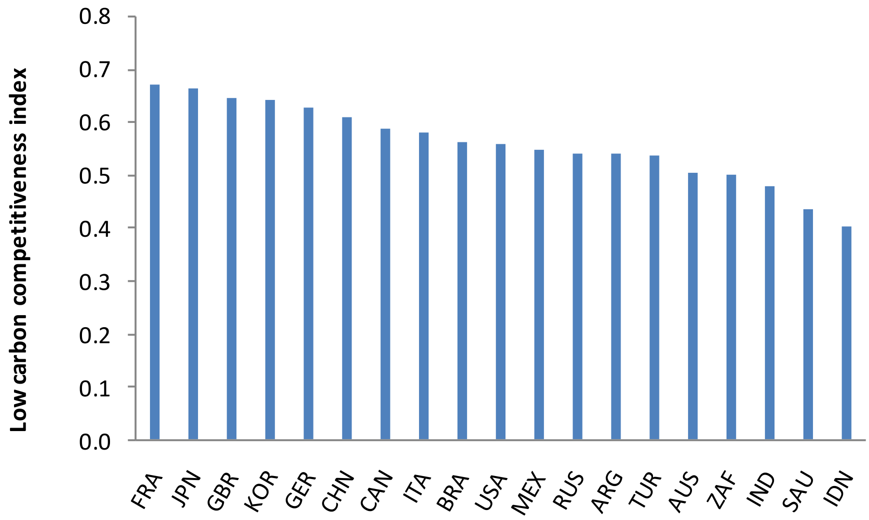
There are three elements to assessing overall low carbon competitiveness: where countries are positioned now, the rate at which this is changing, and the scale of the challenge they face. This report therefore compares the performance of the G20 countries along three key metrics:

[1] There are nineteen country members of the G20 plus the EU. The performance of the EU as a whole is not considered in this report.

[2] GDP calculations based upon IMF data for 2008, while the emissions calculations are based upon World Resources Institute data for 2000 and include land use change and forestry.

- *the low carbon competitiveness index*: measuring the current capacity of each country to be competitive and generate material prosperity to its residents in a low carbon world, based upon each country's current policy settings and indicators;
- *the low carbon improvement index:* the extent to which countries are demonstrating an ability to improve their carbon competitiveness as they grow;
- *the low carbon gap index*: the difference between this rate of improvement and the rate required if that country, given its projected economic growth, is to succeed in meeting its share of the required carbon reductions for atmospheric concentrations of greenhouse gases to be stabilised at 450 ppm (parts per million) CO_2e.

Figure 1 European and East Asian countries do well in the low carbon competiveness index

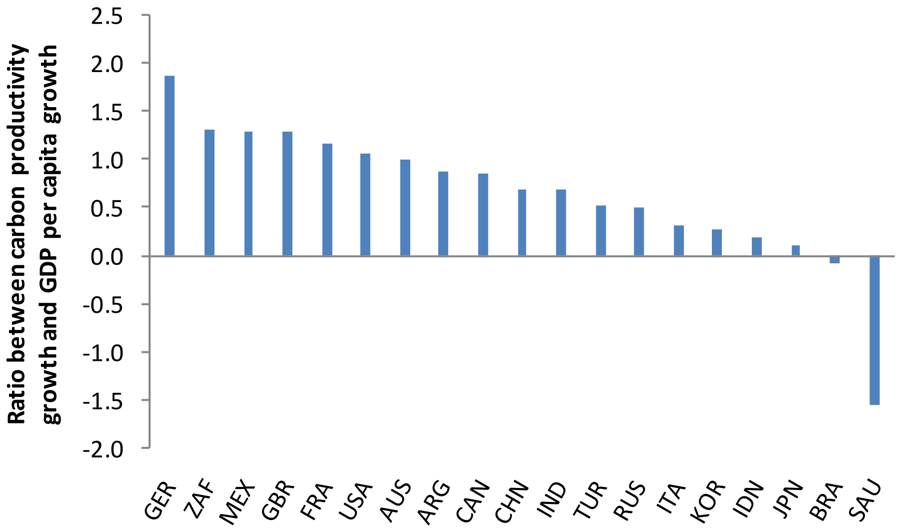


Source: Vivid Economics calculations

Generally speaking, countries that have both high levels of GDP per capita and have acknowledged the need to make adjustments to their economies to allow for low carbon growth come towards the top of the **low carbon competitiveness index**. This index is charted in Figure 1. By contrast, countries towards the bottom of the index are Australia and non-Annex I nations that are heavily dependent upon carbon intensive production for income.

The extent to which countries are improving (or retracting) in their carbon competitiveness is potentially more important than their current position. Rich countries may be failing to make any significant improvement in this capacity. Conversely, countries with low GDP per capita may not have high levels of carbon competitiveness, but nevertheless may be making significant progress towards having such. This is captured in the low carbon improvement index which is shown in the figure below.

Figure 2 Germany comes top of the low carbon improvement index, but some industrialising economies also perform well

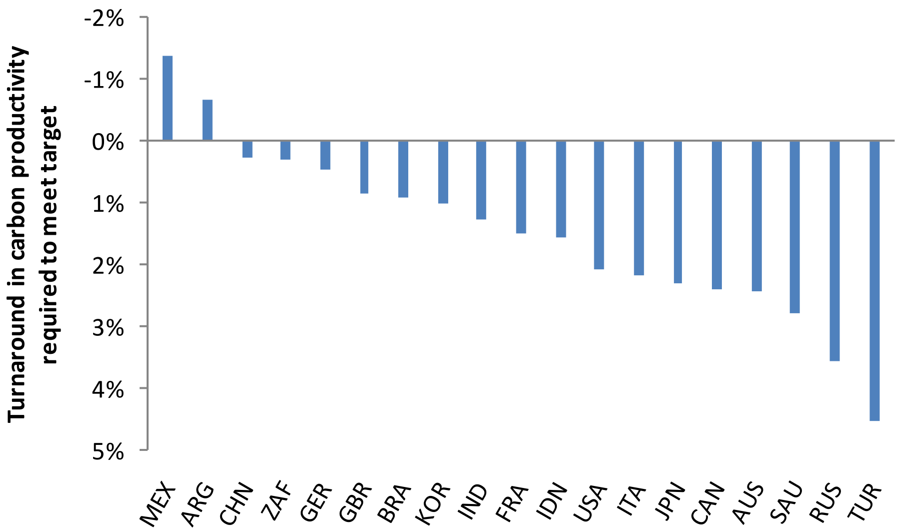


Source: Vivid Economics analysis of World Bank data

While Germany comes top of this index, a number of middle income countries are improving their carbon productivity at a faster rate than some advanced economies. In particular, South Africa and Mexico are second and third in this index. These three countries have demonstrated, in the recent past, an ability to both grow their economies while also significantly increasing the amount of GDP obtained from each tonne of carbon dioxide emitted. By contrast, recent economic growth in Saudi Arabia has only been achieved through increasing the carbon intensity of its economy. Japan, while highly placed in the low carbon productivity index, has shown little ability to improve its carbon productivity over the period analysed.

Finally, the **low carbon gap index**, shown in Figure 3, compares changes in carbon productivity in each country with the rate of carbon productivity growth *required* if ambitious targets for greenhouse gas emission reductions are to be achieved given (country-specific) projected economic growth rates. To do this, the IPCC reduction scenarios which envisage eventual stabilisation of atmospheric emissions at 450 ppm CO_2e are used. This requires global growth in emissions to peak at around 25 per cent above 1990 levels by 2020 with differential targets for developed (Annex I) and industrialising (non-Annex I) countries. Without early action, the economies with the largest gaps are likely to find the transition to an emissions constrained world relatively more difficult and costly both economically, and potentially also socially and politically.

Figure 3 Only two G20 countries are currently improving carbon productivity quickly enough to meet carbon reduction targets



Source: Vivid Economics Analysis of World Bank data

Two countries are currently improving their carbon productivity at a rate which is high enough to meet the global emissions reduction goal, given expected growth rates of population and GDP: Mexico and Argentina. Both these countries should experience continuing increases in carbon productivity, due to a combination of carbon efficient growth and lower emission reduction targets by virtue of being non-Annex I countries. China, South Africa and Germany are close to being on track. Other countries need to improve their rate of carbon productivity growth. The largest turnarounds in carbon productivity are required by Australia, Turkey, Russia and Saudi Arabia.

The large number of rapidly industrialising nations at the top of this index shows that some countries are growing fast and are doing so in a way consistent with the projections for emissions underpinning these IPCC scenarios. Annex I countries generally have more work to do than non-Annex I countries, mainly due to the tougher presumed emissions targets. However this pattern is not universal. Some Annex I countries, Germany and the UK, are close to making sufficient progress. Conversely, despite less strict emissions targets, some non-Annex I countries, such as Saudi Arabia, require major changes of direction.

This report shows that there is a wide range of performance amongst the G20 countries when it comes to low carbon competitiveness. These performances reflect different starting points and levels of national ambition, but show that there is potential for all countries to improve and move towards low carbon best practice.

Improvements in carbon productivity need not be at the expense of economic growth. This is true in both developed and industrialising economies. Countries as diverse as Germany, South Africa and Mexico have all shown an ability in the recent past to decouple economic growth from carbon emissions. They demonstrate what is possible for other G20 countries and provide confidence that a global deal to reduce emissions is achievable without compromising on growth and covering developed and industrialising nations.

However, much remains to be done. Only two G20 countries are currently on a trajectory consistent with stabilisation of atmospheric emissions of CO_2e at 450 ppm. While a number of other countries, including China, need only reasonably modest changes to rectify this, many other countries remain well off the pace required if dangerous climate change is to be avoided. The longer these countries take to achieve these turnarounds, the more costly the eventual transition will be.

Contents

List of tables

List of figures

1 Introduction

A carbon[3] constrained future will alter the economic position of every country, producing winners and losers. The differential impact of these changes will mean that, along with changes in production costs and consumer demands, global patterns of trade will shift. Economic modelling has suggested that those countries that are relatively less emissions intensive, or move first to reduce emissions, will gain a relative advantage as the world reduces its greenhouse gas emissions (Commonwealth Treasury, 2008). In sum, countries' competitiveness will change. Although competitiveness is a complicated concept and, moreover, ideas of competitiveness themselves also need to adapt to a low carbon world, countries which are prepared for these shifts are likely to be better placed to secure the well-being of their residents.

It is important to acknowledge both the conceptual difficulties of defining competitiveness at the national level, as well as the challenges of capturing this concept through the use of indices. Nonetheless, this report attempts to take account of these challenges. It uses a data-driven approach to defining competitiveness in practice, using econometrics where appropriate, to help assist in the construction of the indices. Moreover, it seeks to expand the conceptual boundaries of competitiveness by explicitly bringing a much-need focus on efforts to shift to a low emission world and considering both developed and developing countries in a comparable action framework.

The next section of this report will discuss and define the concept of competitiveness in a low carbon future. The definition of low carbon competitiveness for a country will be taken to be the ability of a country to generate material prosperity (proxied by economic output) to its residents in a carbon constrained world. Climate change is a long-term problem where actions can have impacts both now and in the future. As such, it is of interest to consider **how well countries are positioned currently**, **the rate at which they are changing their position** and **the rate at which they need to change in order to meet stabilisation scenarios**. Section 3 considers the first of these, while Section 4 presents a measure of the growth rate of carbon productivity and sets this in a context of what is required for an eventual stabilisation at 450 ppm CO_2e. Technical details and further detailed commentary on the methodological approach are contained in a series of appendices.

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[3] Throughout the document, except where stated, references to carbon (dioxide) relate to emissions of the six greenhouse gases identified by the IPCC, excluding those from the land use change and forestry sector, expressed on a CO_2e basis.

2 Defining low carbon competitiveness

2.1 Standard definitions of competitiveness

Before turning to the specific question of how to define 'low carbon competitiveness', it is necessary to first understand the different meanings that are often attached to the word 'competitiveness'.

At a firm level, competitiveness may refer to the relative costs of production of the same good as compared to other firms; however, this definition does not translate easily to the level of a country. If an individual firm has lower production costs than another it will, depending on the structure of the market, take market share off the higher cost firm. The same is not true at a country level. This is encapsulated by the critique of Krugman (1993):

"...international trade is not about *competition*, it is about mutually beneficial exchange. Even more fundamentally...imports, not exports, are the purpose of trade. That is, what a country gains from trade is the ability to import things it wants. Exports are not an objective in and of themselves: the need to export is a burden that a country must bear because its import suppliers are crass enough to demand payment."

The difference arises because of the distinction between absolute and comparative advantage in international trade. Even if one country has a lower (absolute) cost of producing every good, it will still gain from trade with another country, with higher costs, provided the more costly country has different *relative* production costs between goods. However, while the implications of language need to be considered, the Krugman critique does not mean that countries all achieve the same benefits from trade, or that changes in economic conditions do not change the absolute and relative gains that can be made.

One objective of economic policy in a country should be to provide well-being to its current and future residents. Trade is useful to a country in that it allows its residents to have a higher standard of living than they could enjoy if they had to rely solely on domestically produced goods. It is for this reason that trade is so closely associated with international competitiveness. Measuring competitiveness as being related to the standard of living is a natural way to consider the topic at the country level. The World Economic Forum, in *The Global Competitiveness Report 2008-2009*, notes that a nation's level of competitiveness reflects "the extent to which it is able to provide rising prosperity to its citizens." This is also the meaning ascribed to competitiveness at the level of the country in this report.

2.2 Definitions of competitiveness need to be adapted for a low carbon future

Climate change has the potential to have significant impacts on living standards, not only through climatic changes but also because of shifts in demand from high carbon intensity goods to low carbon intensity goods. There will be significant economic opportunities and costs that will result from such a shift, and countries will differ in their level of exposure to these risks and their capacity to exploit these opportunities. Those nations that can produce goods and services with a lower emissions intensity will likely generate higher profits for their goods because, assuming that there is at least an implicit price for carbon emissions, they will enjoy lower production costs. This is one important basis for being concerned about competitiveness in a low carbon future.

In a more specific way, we propose to use the level of Gross Domestic Product (GDP)[4] per tonne of emissions (called 'carbon productivity' by some, for example, McKinsey Global Institute (2008)) as the starting point for assessing a country's carbon competitiveness. While it is widely recognised that GDP is an imperfect measure of overall prosperity (Nordhaus (2000), Neumayer (2001), Commonwealth of Australia (2008)), it is undoubtedly a major determinant of living standards, particularly in the post-WWII era (Easterlin (2000)). While acknowledging its imperfections, this report uses GDP as a proxy for prosperity.

Under the presumption that global emissions will be constrained in the future, those countries which can produce more GDP from each tonne of emissions will be able, other things being equal, to provide a greater level of well-being to their residents than those countries that produce less GDP for each tonne of emissions. This logic holds regardless of the distribution of any global emissions cap across countries.[5] Climate science suggests that it is the total level of emissions that needs to be limited, and so the level of prosperity that can be delivered is limited by the relationship between prosperity and a tonne of emissions.

[4] GDP is a measure of the market value of the output (goods and services) generated by an economy which is exchanged through market transactions.

[5] While the allocation of emission allowances under a global cap is an allocation of valuable property rights, and so is effectively a distribution of wealth that will affect the level of wealth in a particular country, for any given level of allocation, a particular country will be better placed to generate material prosperity if it can produce more GDP for each unit of allowances it is allocated.

The baseline for the analysis is low carbon competitiveness under a universal carbon constraint. Such a carbon constraint need not be explicit nor necessarily implemented through taxation or emissions trading. It is, however, equivalent to an assumption that all countries take comparable action such that there is no incentive to shift emissions from one jurisdiction to another solely as a result of climate policy.

This is the adopted baseline because preparation for a low carbon future that is consistent with avoiding dangerous climate change will require universal action, and in order to abstract from any transitory effects due to different countries regulating carbon emissions before others. This is not to suggest that such matters are not of importance to the broader debate. Issues of trade exposure, often referred to as carbon leakage, can have large impacts on the effectiveness of emissions reduction schemes in the short run and the incentives of countries or regions to adopt or strengthen them. For example, see Vivid Economics (2008a) for a discussion of these issues in relation to aviation in the EU ETS or Reinaud (2008) in the context of heavy industry more generally.

However, in the long-run, as the world takes more ambitious action on climate change (such as wider application of carbon pricing or emissions trading schemes), disadvantages from being an early mover may be reduced and even reversed if, for example, there are advantages by way of intellectual property development or the early capture of lucrative new green markets. In short, this report is focused on positioning for long-run competitiveness, and the analysis is therefore conducted assuming that the future into which we are projecting carbon competitiveness is one in which there is a universal, or near universal, carbon constraint.

2.3 Assessing low carbon competitiveness

This report constructs three measures to assess low carbon competitiveness.

The low carbon competitiveness index captures **the capacity of each country to generate material prosperity to its residents in a low carbon future**, based upon each **country's current policy settings and indicators**. Variables and weightings for the index are chosen on the basis of a statistical analysis of the relationship between various indicators and carbon productivity. Variables are included in the index if they are found to have a sufficiently strong statistical relationship to carbon productivity, and their weighting in the index is proportionate to the size of their impact.

The advantage of constructing an index which considers a large number of variables and weights them according to their association with carbon productivity is twofold.

- First, while synthesising numerous pieces of information into an overall performance measure, it also allows identification of reasons for divergent performance.

- Second, it also allows identification of where a country has developed policies, or its economy has otherwise changed, in such a way that it will be able to provide more prosperity for its residents in a low carbon world but which due to the lagging nature of carbon emissions data may not be fully captured in the data.

Despite the advantages of developing an index such as this, there are also advantages of directly considering differences in carbon productivity between countries. One of the most important of these is that the absolute movements of countries over time can be observed and compared against each other and against policy objectives. Both the science of climate change (CO_2 is a stock pollutant) and policy interest dictate that as much, if not more, focus should be placed on a country's direction of travel. A country may currently be highly carbon competitive, in that it is able to generate high levels of GDP per tonne of emissions, but doing little to improve its ability to generate GDP from each tonne of emissions. Conversely, a country may not be able to currently generate much prosperity for its residents from each tonne of carbon but nonetheless be on a trajectory that will significantly improve its carbon competitiveness.

In fact, arguably more important for prosperity than changes in carbon productivity *per se* are changes in carbon productivity as GDP per capita increases. Although growth rates will differ, it is likely that all countries of the G20 will experience increases in the level of GDP per capita over the coming decades. Thus a key consideration is whether countries are able to decouple economic growth, as defined by GDP per capita, from carbon intensity, as defined by GDP per tonne of emissions. Countries which are increasing carbon productivity faster than they are increasing GDP per capita will be experiencing both higher levels of prosperity and lower levels of emissions per capita.

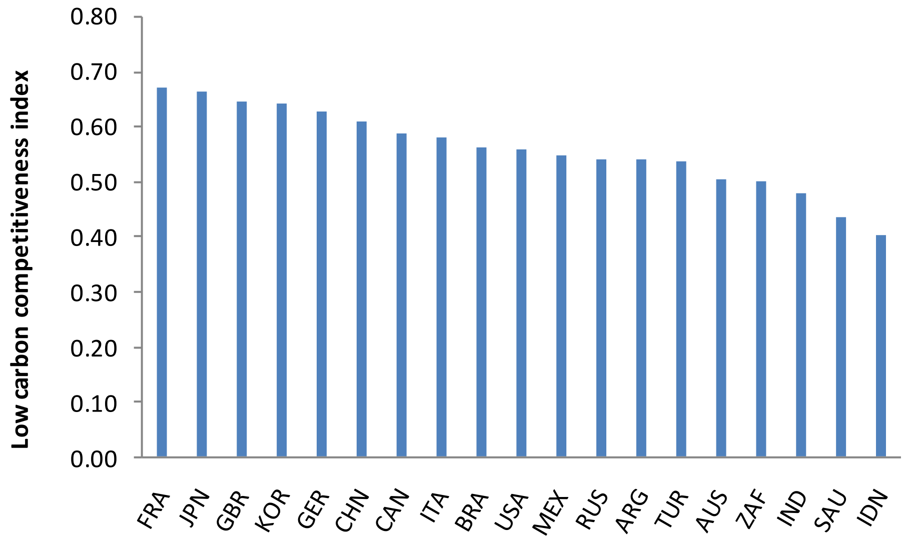
Consequently, the low carbon improvement index captures the rate at which countries are **shifting to a low carbon economy** and, thereby, **improving their ability to be competitive**. This uses statistical analysis of the recent historical relationship between carbon productivity and GDP per capita to estimate, for each country, the rate at which it is has been able to reduce the carbon intensity of its economy as it grows.

The final measure, the low carbon gap index, considers the **turnaround or improvement required in carbon productivity growth if ambitious global targets on emission reductions are to be met**. This measures the gap between a country's current rate of carbon productivity growth and that which is needed if these targets are to be met, at the same time that the country grows its economy as currently projected. It can be considered a measure of how far above or below a country is from a 'comparable action' benchmark.

3 The low carbon competitiveness index

This section shows that, of the G20 countries, France and Japan are currently best placed to be competitive in a low carbon future, and that Saudi Arabia and Indonesia are worst placed. The rankings from the index are presented in Figure 4 below. This section also outlines the process for constructing this index. It briefly explains how the variables within the index were chosen and how the weight attached to each variable was determined.

Figure 4 European and East Asian countries are ranked highly in the low carbon competitiveness index



Source: Vivid Economics calculations

3.1 Variable selection and construction of the index

An initial data collection exercise provided 36 variables which were considered likely to be linked to a country's low carbon competitiveness and which had sufficient coverage across all countries and across a sufficient number of years. These variables reflected the fact that a country's low carbon competitiveness can be improved either by reducing its carbon emissions for any given level of output (e.g. by switching from 'dirty' to 'clean' electricity generation) or by increasing its level of output for any given level of emissions (e.g. by improving the education opportunities for its residents).

The variables were assigned to one of three categories that were chosen to represent different, although clearly related, elements which will determine performance in a low carbon future: sectoral composition, early preparation and future prosperity.

- The **sectoral composition** category captures how well, or otherwise, the composition of the economy is currently structured towards less emissions intensive activities. It is included because the relative prices of output in different industries will change systematically. Countries whose economies are more heavily weighted towards sectors which will experience lower demand will be relatively worse off. For example, the measure of the balance of emissions embodied in trade, similar to the carbon intensity of exports, developed by Peters and Hertwich (2008) is part of this category, as is transport sector energy consumption.

- **Early preparation** variables include indicators reflecting the steps that countries have already taken to move towards a low carbon economy. They are included for two reasons. First, the cost of using and developing low carbon technologies can be expected to fall over time as more experience is gained. This effect is also known as learning by doing and is a well established phenomenon that has been observed in many industries, notably in the power sector (McDonald and Schrattenholzer (2001)). Countries which are early adopters of energy efficient or low carbon technologies will experience higher rates of learning and so will be better placed to generate material prosperity in the future. Second, the costs of shifting to a high carbon economy will be higher as the period over which the shift has to occur becomes shorter. For example, shifting to low carbon electricity is more costly over a shorter time period because the capital in existing power stations has to be retired early. For these two reasons, countries which take early action will have higher standards of living in a low carbon future. The carbon intensity of electricity and investment in sustainable energy businesses are examples of indicators in this category.

- The final category consists of variables which will determine **future prosperity** through their impact on the level of production of goods and services (broadly defined) per capita. The future level of production will be determined by the future level of capital in the economy. Accordingly, we include measures of the rate of change of human capital, physical capital and natural capital from the World Bank (2006). The measure of natural capital captures the change in a country’s stocks of resources, such as agricultural land, minerals and forests. If countries deplete their stock of natural capital, it reduces their capacity to produce goods and services (such as timber or clean water) from the natural environment in the future. The level of GDP per capita is included, as prosperity is highly persistent over time, as is population growth, to reflect the fact that countries with higher populations will need to divide the output from the fixed stock of emissions over a greater number of people.

With this data, statistical techniques were used to establish which of these variables, in the recent past, has had the strongest association with low carbon competitiveness - defined as GDP per tonne of emissions in this report. It should be emphasized that association does not necessarily imply causation: in many cases the variables should be considered as proxies for the underlying, but more difficult to measure, driver of carbon productivity; the efficiency of oil refining can be seen as a proxy for the efficiency of the industrial sector as a whole, while the percentage of electricity distribution losses is a proxy for the overall sophistication of the electricity grid (necessary if decentralized clean electricity generation is to be effectively harnessed).

Those variables which were both deemed to be positively associated with a good performance and reached a certain threshold of significance were then selected. These variables are presented in Table 1. The variables which were omitted as a result of this process are in Table A1 of Appendix B.

In order to translate these criteria into a single index, weights need to be assigned to each component. This is not a straightforward task, and there is no universally accepted method for doing this (see Morse and Fraser (2005) and Esty et al (2005) for a discussion of some of the issues). The approach taken by this report is to use the econometric analysis to understand the relative importance of each individual variable within the index. As each individual variable is allocated to one of the three categories, the appropriate weight for each category can be ascertained as the sum of the individual weights of its component indicators. Then, within each category, all indicators have been weighted equally. The weights derived from this exercise are presented in Table 2. Appendix B discusses the approach taken to the weighting in more detail.

Due to the econometric approach taken to the weightings the index is cardinal; that is, the size of the gap between countries provides information on the relative distance between them. Because the values of the indicators were all transformed to be between zero and one, a difference of 0.01 in the index could be interpreted as the distance a country would move if all of its indicators moved one per cent closer to best practice.

Table 1 A total of nineteen variables were included in the index

Variable	Definition	Source	Is higher better?	Category
Transport sector energy consumption per capita	‘000 tonnes of oil equivalent (toe) per capita	International Energy Agency (IEA)	No	Sectoral Composition
Deforestation rate	% of total forest cover	World Development Indicators (WDI)	No	Sectoral composition
Share of high technology exports	% of total exports	WDI	Yes	Sectoral Composition
Size of road transport sector	Cars per 1000 people	WDI	No	Sectoral Composition
Balance of emissions embodied in trade	as % of total emissions from production	Peters and Hertwich (2008)	No	Sectoral Composition
Air freight	Million tonne-kilometres	WDI	No	Sectoral Composition
Clean energy production	% of total energy use	IEA	Yes	Sectoral Composition
Efficiency of oil refining	Net energy input into oil refineries per unit of output (‘000 toe)	IEA	No	Early Preparation
New sustainable energy investment	$US equivalent listed on the local stock exchange	New Energy Finance	Yes	Early Preparation
Electricity distribution losses	% of total electricity generated	IEA	No	Early Preparation
Annual growth in greenhouse gas emissions	Change in emissions (%)	World Resources Institute (WRI)	No	Early Preparation
Price of diesel fuel	$US/litre	GTZ	Yes	Early Preparation
Carbon intensity of electricity	CO_2 per kWh	WRI	No	Early Preparation
Human capital	Education expenditure as % of GNI	WDI	Yes	Future Prosperity
Physical capital	Rate of fixed capital formation as % of GNI	WDI	Yes	Future Prosperity
Natural capital	Depreciation as a % of GNI	WDI	No	Future Prosperity
Population growth	%	Penn World Table	No	Future Prosperity
GDP per capita	2000 $US per person	Penn World Table	Yes	Future Prosperity
Cost of business start-up procedures	% of GNI per capita	WDI	No	Future Prosperity

Source: World Development Report 2005, The World Bank, © 2005; International Energy Agency; World Resources Institute; New Energy Finance; GTZ; Penn World Table and Peters and Hertwich (2008)

Table 2 The future prosperity category has the highest weight in the index

Category	Early Preparation	Sectoral Composition	Future Prosperity
Weight	0.194	0.349	0.457

Source: Vivid Economics analysis

3.2 Key results

Table 3 presents the low carbon competitiveness index. The countries which are best placed to generate material prosperity to their residents in a low carbon future are those countries which are currently wealthy and, in various ways, have demonstrated a commitment to energy efficiency and low carbon energy production. The top four positions are held by France, Japan, the United Kingdom and South Korea. The index suggests that these are all countries which will be able to produce high levels of GDP per unit of emissions in the future. Those countries near the bottom of the index are generally non-Annex I nations which are heavily dependent upon carbon intensive natural resource production for income. Indonesia is ranked 19th, while Saudi Arabia is ranked 18th.

It can take some time for changes in the economic structure or policy environment to reflect themselves in emissions data, and so while this ranking is similar to a ranking of current carbon productivity it is not identical.

3.3 Country summaries

Below, the reasons for the performance of each country and potential ways of improving its position in the index are discussed.

Argentina (ARG)

Argentina is ranked 13th out of 19 countries. It has the lowest use of air freight out of any of the countries which improves its ranking in the sectoral composition category, but is consistently ranked in the bottom half across all the indicators.

Australia (AUS)

Australia is ranked 15th out of 19 countries and is the lowest ranked of the Annex I countries of the Kyoto Protocol. High levels of wealth and expenditure on schooling lead it to perform well on the future prosperity category. On the other hand, this is more than counteracted by other indicators: its carbon intensive exports and high levels of car ownership lead it to

Table 3 France comes top of the low carbon competitiveness index

Country	Rank	Index Value	Country	Rank	Index Value
France	1	0.67	Mexico	11	0.55
Japan	2	0.66	Russia	12	0.54
United Kingdom	3	0.64	Argentina	13	0.54
South Korea	4	0.64	Turkey	14	0.54
Germany	5	0.63	Australia	15	0.50
China	6	0.61	South Africa	16	0.50
Canada	7	0.58	India	17	0.48
Italy	8	0.58	Saudi Arabia	18	0.43
Brazil	9	0.56	Indonesia	19	0.40
USA	10	0.56			

Source: Vivid Economics analysis based on various data including New Energy Finance

perform worst in the sectoral composition category. Likewise, its carbon intensive electricity sector and high consumption of transport fuels contribute towards a lower half ranking in the early preparation category.

Brazil (BRA)

Brazil ranks in the middle, coming in at 9th place. Its performance is negatively affected by its low investment in physical capital, and high deforestation and population growth rates. This is partly offset by the fact that it has the lowest CO_2 intensity of electricity production.

Canada (CAN)

Canada is ranked 7th on the basis of a strong all-round performance in the early preparation and future prosperity categories. However, it is one of the lowest ranked countries in the sectoral composition category. It is ranked in the top three countries for low emission electricity, overall use of clean energy and efficiency of oil refining. It is a poor performer on some other indicators though; in particular, Canada has a high level of transport sector energy consumption and high levels of car ownership.

China (CHN)

China attains a ranking of 6th – the highest ranking by a non-OECD country. High rates of reforestation and low transport sector energy consumption lead to a strong performance in the sectoral composition category, but it is a poor performer in the early preparation category due to its rapid recent emissions growth and carbon intensive electricity supply. China has the highest rate of investment in physical capital, and also the second highest share of high technology exports in total exports.

France (FRA)

France tops the index due to a combination of excellent rankings in early preparation and top five rankings in sectoral composition and future prosperity. Its performance is good across all the indicators on these categories, but especially so due to low carbon electricity and low rates of depletion of natural capital. It could improve its score by reducing its reliance on air freight.

United Kingdom (GBR)

The United Kingdom's ranking in third place is driven by its early preparation. Its exports are the least carbon intensive of any of the G20 countries. Other notable contributors are its high prices for transport fuels, high reforestation rates, low cost of business start-up procedures and high investments in sustainable energy businesses. It could improve its ranking by reducing energy consumption in the transport sector, reducing reliance on air freight and increasing physical capital investments.

Germany (GER)

Germany, ranked 5th, follows the pattern of a strong performance by European countries. Its efficient electricity grid and already low rate of growth of greenhouse gas emissions give a strong performance in the early preparation category, while low depreciation of natural capital and high GDP per capita leave it well placed for future prosperity. Like other European countries, it has one of the highest rates of car ownership, use of air freight and energy consumption in the transport sector which all weigh on performance.

Indonesia (IDN)

Indonesia is the worst performer. It combines low GDP per capita, very high rates of deforestation, an inefficient industrial sector and cheap transport fuels. It performs better in terms of its transport sector (low use of air freight, car ownership and energy consumption in transport) and its relatively high investments in physical capital.

India (IND)

India is a poor performer and is ranked 17th. It has the second lowest score in the early preparation category with carbon intensive electricity being distributed via an inefficient grid. It is a low GDP per capita country where the costs of starting a business are high. Conversely, it has a low per capita use of energy in the transport sector.

Italy (ITA)

Italy is ranked 8th. Italy has a good ranking in the sectoral composition category, due to its high rate of reforestation and, for a country of its wealth, low use of air freight. Italy also has efficient oil refineries, low emission intensity exports and expensive fuels. It does, however, have high levels of car ownership and low levels of clean energy use.

Japan (JPN)

High levels of wealth and investment in physical capital give Japan the strongest performance on the future prosperity category and a ranking of 2nd overall. It uses a lot of clean energy and has an efficient industrial sector (as proxied by the efficiency of its oil refining sector). Japan's weakest performance is in the sectoral composition category due to high amounts of air freight, transport fuel consumption and deforestation.

South Korea (KOR)

South Korea is ranked 4th. It has the highest level of high-technology exports, the most efficient electricity transmission network, high rates of investment in physical capital, and low rates of depletion of natural capital. It could improve its performance by reducing the cost to start up a business and reducing its reliance on air freight.

Mexico (MEX)

Mexico is ranked 11th. It performs in the top five of the G20 in the sectoral composition indicators thanks to low car ownership and low use of air freight, but is a weak performer in the other two categories. Major contributors to its poor performance are high deforestation, low prices for transport fuel and low efficiency in oil refining.

Russia (RUS)

Russia is ranked 12th in the index. Low business start-up costs and low use of air freight aid performance, but carbon intensive exports, a high level of depletion of natural capital and cheap transport fuels detract from its performance. It does, however, have a relatively low carbon intensity of electricity production.

Saudi Arabia (SAU)

Saudi Arabia is ranked 18th. It has a weak performance across all categories and is the bottom ranked country in a number of indicators including use of clean energy, price of transport fuels, population growth, depletion of natural capital and share of high technology exports. One exception to this is investment in human capital, the proportion of education expenditure in GNI, for which Saudi Arabia ranks 1st.

Turkey (TUR)

Turkey is ranked 14th, just ahead of Australia. It performs well in terms of low transport sector energy consumption, air freight and deforestation. Turkey has a poor performance in the future prosperity category with low investment in education and high population growth.

United States of America (USA)

The United States is ranked 10th; four places behind China and just in front of Mexico. It achieves a top five ranking in the future prosperity category, but has the highest use of energy in the transport sector and the highest use of air freight. It also performs poorly because of high car ownership and relatively low levels of investment in physical capital. Its ranking is boosted by having the highest amount of investment in sustainable energy businesses and a high share of high technology exports, along with low business start-up costs.

South Africa (ZAF)

South Africa comes near the bottom of the index at 16th out of 19. It has low use of air freight and low transport sector energy consumption, but the most carbon intensive exports, high carbon intensity electricity and the second lowest rate of investment in physical capital.

3.4 Sensitivity to category weightings

One of the most controversial aspects of constructing an index such as this is the choice of weightings used to aggregate the individual indicators into a single index (Morse and Fraser (2004)). The use of econometrics to guide the weightings has minimised the extent to which they have been based upon subjective judgement; however, there are inevitably different views that could be taken as to the weights which should be applied.

In order for the reader to be able to see the sensitivity of the results to differences in the weightings, and also because it is of interest of itself, Table 4 presents the rankings for the nineteen countries of the G20 separately for each of the four categories. It can be seen that some countries perform similarly across all four categories: Saudi Arabia is an example of this. Other countries, such as Brazil and China, perform very well in some categories and poorly in others. The ranking of these latter countries will therefore be somewhat more sensitive to the weightings applied.

Table 4 Rankings can differ substantially between the three categories

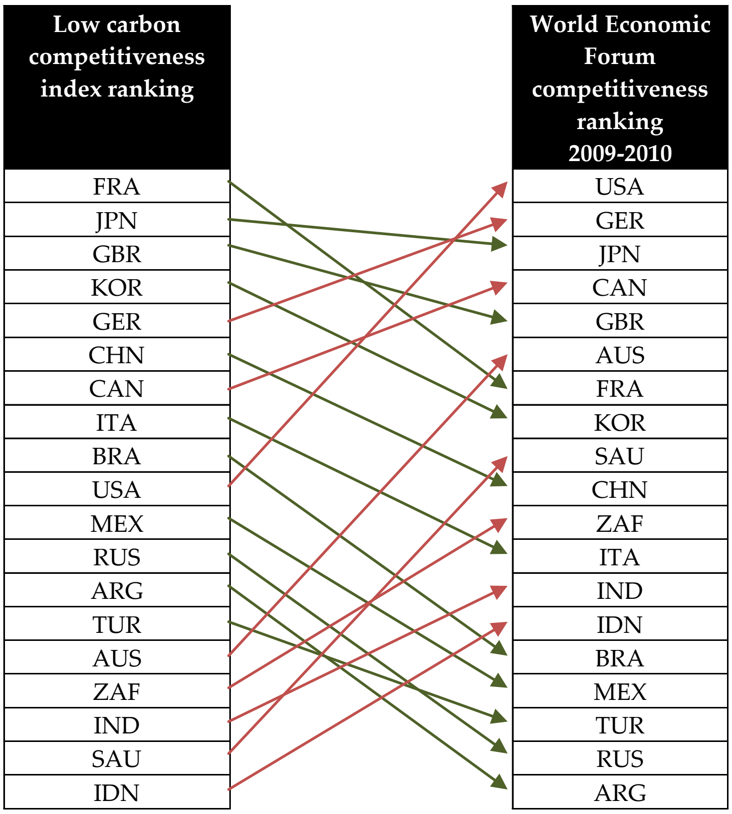
Country	Overall Rank	Early Preparation Rank	Sectoral Composition Rank	Future Prosperity Rank
France	1	1	5	5
Japan	2	4	9	1
United Kingdom	3	3	7	4
South Korea	4	5	3	7
Germany	5	2	13	3
China	6	14	1	9
Canada	7	6	15	6
Italy	8	7	12	10
Brazil	9	12	2	15
USA	10	8	18	2
Mexico	11	19	4	11
Russia	12	13	11	12
Argentina	13	15	8	13
Turkey	14	10	6	16
Australia	15	9	19	8
South Africa	16	11	16	14
India	17	18	10	18
Saudi Arabia	18	17	17	17
Indonesia	19	16	14	19

Source: Vivid Economics analysis

3.5 Comparison with World Economic Forum competitiveness rankings

The World Economic Forum (WEF) compiles a well known index of competitiveness known as the global competitiveness index. The WEF index does not explicitly consider climate change as part of its analysis, although it does consider a country's capacity to implement effective environmental policy. The WEF index also considers a wider range of countries. Nonetheless, it is instructive to compare the two rankings. Figure 3 shows the rankings of countries in the low carbon competitiveness index with the order in which the G20 countries are ranked by the WEF. It can be seen that there is no systematic relationship between the two, indicating that the two indices are capturing different elements of performance. The countries that do relatively better in the low carbon competitiveness index are France, Japan, the United Kingdom, South Korea, China, Italy, Brazil, Mexico, Russia, Argentina and Turkey. The opposite is true for Germany, Canada, the USA, Australia, South Africa, India, Saudi Arabia and Indonesia.

Figure 5 The low carbon competitiveness ranking is different from the World Economic Forum competitiveness ranking



Source: Vivid Economics and the World Economic Forum

4 The low carbon improvement and low carbon gap indices

The low carbon competitiveness index is designed to explain how well countries are currently positioned to generate material prosperity to their residents in a low carbon future. The capacity of countries to generate material prosperity in this context is not static, however, and will be changing over time. This section considers the speed at which countries are making these improvements and whether it is currently quick enough to meet the given targets for emissions reductions.

The low carbon competitiveness index gives insight into what policies or other factors might be leading a country to have a particularly strong or weak performance. In this section, the rate of improvement in carbon productivity, and its relationship with economic growth, is assessed directly rather than through examination of a series of indicators. This approach gives the ability to assess a country's performance compared to its directly measured outcomes and allows for an assessment of performance against policy goals.

As an intermediate step for framing the analysis on the rate of improvement, this section begins by considering the existing relationship between carbon productivity and GDP per capita levels (rather than their growth rates) in the G20 countries. As appendix C sets out in more detail, while not perfect, GDP per capita is a reasonable proxy for conventional measures of productivity.

Following this, the relationship of carbon productivity and GDP growth will be used to construct the **low carbon improvement** index. In this index, countries are ranked according to how much their carbon productivity changes as their economies grow. Germany ranks first: a one percentage point increase in GDP per capita has historically been associated with a nearly two percentage point increase in carbon productivity. This relationship is also strong in Mexico and South Africa; although, these countries start from a position of lower levels of carbon productivity. By contrast, Brazil and Saudi Arabia have only achieved economic growth in the recent past through increasing the carbon intensity of their economies.

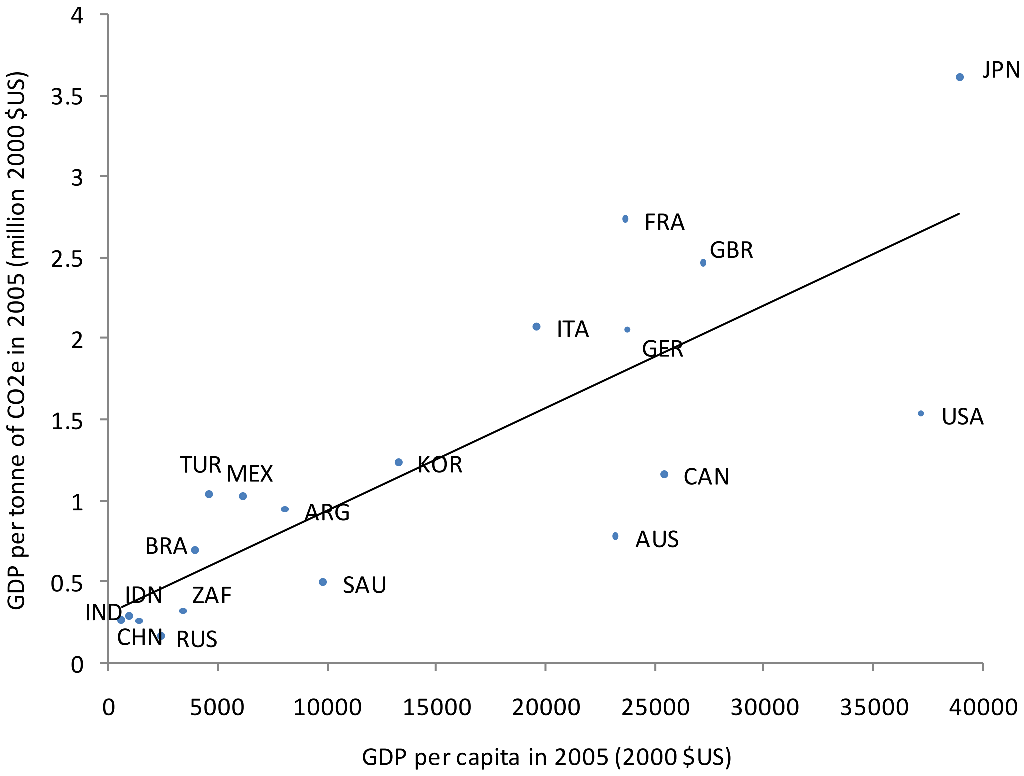
The **low carbon gap** index considers whether countries are improving their carbon productivity quickly enough if they are to meet their share of the required emissions reductions for atmospheric concentrations of carbon dioxide emissions to be stabilised at 450 ppm. This takes account of the recent historical relationship between economic growth and carbon productivity, projected future economic and population growth rates, and differentiated responsibilities for emissions reductions between Annex 1 and Non-Annex 1 countries. The results of these calculations show that currently only Mexico and Argentina are improving the carbon productivity of their economies sufficiently quickly as they grow. All other countries in the G20 need to improve their carbon productivity growth rate.

4.1 The relationship between carbon productivity and GDP per capita

The relationship between carbon productivity and GDP per capita in 2005 is presented in Figure 8. While there is a clear relationship between the two variables, the level of GDP per capita is far from being a perfect predictor of a country's carbon productivity. The black line in Figure 4 represents a line of best fit (i.e. a linear regression) relating GDP per capita to carbon productivity. While the necessarily small sample size of 19 countries means there is a need to be cautious with any interpretation of this line, it could be considered to represent the performance that would be expected by an 'average' country for any given level of GDP per capita. The vertical distance between the line and each country's carbon productivity could be thought of as indicating the effect of country-specific factors, such as climate change policies.

Countries that had higher carbon productivity in 2005 than would be expected for their income levels include Italy, France and Turkey. Conversely, Russia, Saudi Arabia and Australia are among those countries which have lower levels of carbon productivity as compared to other countries with similar levels of GDP per capita. The chart also illustrates differences between countries with broadly similar prosperity levels. For instance, consider two pairs of countries: Japan and the USA, and France and Australia. The two countries in each of these pairs have broadly similar levels of GDP, yet in both cases the former countries (Japan and France) extract about three times as much GDP for each tonne of emissions as the latter countries (the USA and Australia). The comparison between Australia and Canada is also instructive: although both are geographically large countries with resource intensive economies (and hence both fall below the average line), Canada consistently achieves a higher level of GDP per tonne of carbon for a given level of GDP per capita.

Figure 6 Countries with high carbon productivity also have high GDP per capita



Source: Vivid Economics calculations from World Bank and World Resources Institute data

It should be noted that countries which rank highly in the low carbon competitiveness index of Section 3 are often, but not always located above the 'average' line. This difference arises because the current level of GDP is not the only factor which will determine future carbon competitiveness. For example, China has a low level of GDP per capita, but very high levels of investment in physical capital and low population growth, and so performs better in the low carbon competitiveness index than Figure 6 would suggest if considered in isolation.

4.2 The relationship between carbon productivity growth and GDP per capita growth

While Figure 6 shows where countries were positioned at a particular historical point in time, it is the rate at which carbon productivity changes with income which will have more influence over the position of countries as they grow. Figure 7 captures this latter concept.

This figure presents a scatter plot with GDP per capita on the horizontal axis and GDP per unit of emissions on the vertical axis. For every year from 1990 to 2005, each country is represented by a labelled point. Therefore, by looking at the set of points belonging to each country, that country's relationship between its economic growth and its carbon productivity growth over that period can be ascertained.[6]

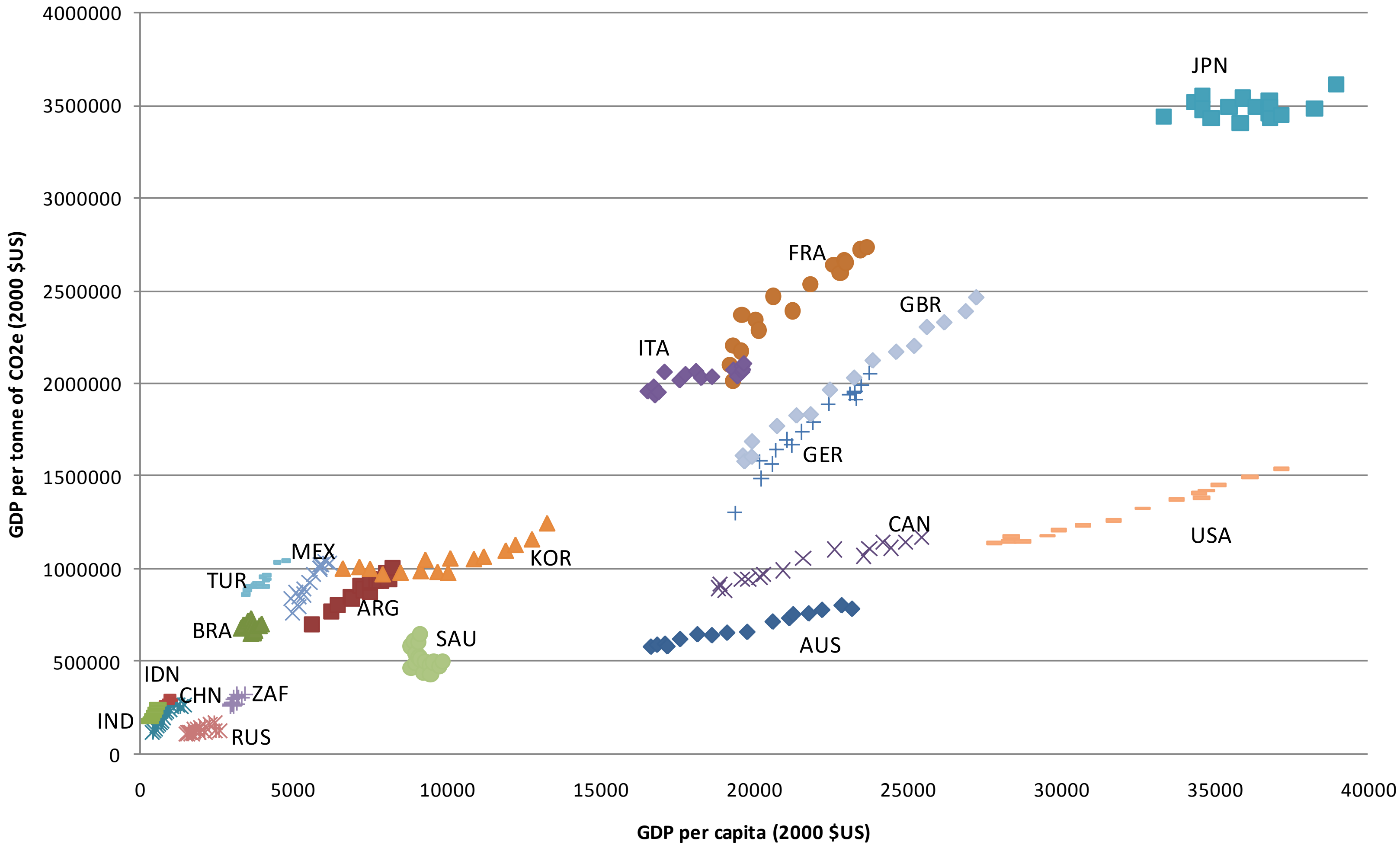
The figure shows, for instance, that while Japan has the highest measured carbon productivity it has shown very little improvement in its carbon productivity over the last 15 years. Conversely, France, Germany and the UK have been able to combine GDP growth with improvements in carbon productivity. Within non-Annex I countries, South Africa, Mexico and China have combined economic growth with improvements in carbon productivity while Indonesia and Turkey have been less successful. Saudi Arabia's recent economic growth has been associated with an *increase* in carbon intensity.

Figure 7 also demonstrates that a number of countries have exhibited a relationship between carbon productivity and GDP per capita which has been changing over time. China experienced high rates of GDP per capita growth over the entire period, but, despite achieving rapid carbon productivity growth between 1990 and 2000, its carbon productivity has since stagnated. South Korea shows the opposite pattern: little carbon productivity growth in the 1990s, but accelerating improvements since then. South Africa and Russia have also had a period of low carbon improvement in the early 1990s and a period of faster improvement since then. In these cases the low improvement occurred in a period when the economy was contracting, and so reflects the fact that carbon emissions were not falling as fast as GDP. Since both these countries resumed growth, carbon productivity has been improving with GDP per capita. For all countries, the results discussed below relate to the average performance over the period. For Russia and China, in particular, the calculations will under- and over-state, respectively, their low carbon position if more recent performance turns out to be sustained.

Garnaut et al (2008) emphasise the importance of recent changes to emissions growth trajectories, and it is likely that at least some of the recent deteriorations in carbon productivity, such as that of China, will be sustained unless concerted efforts are made by national governments.

[6] Figure A1, in Appendix D, presents this same graph on a logarithmic scale so that the cluster of countries at low levels of GDP per capita can be more clearly seen.

Figure 7 The relationship between carbon productivity and GDP per capita varies widely across countries



Source: Vivid Economics analysis of World Bank data

Using the data set out in Figure 7, it is possible to estimate the change in carbon productivity that would be expected if GDP per capita were to increase by one per cent in each G20 country.[7] The results of this calculation provide the **low carbon improvement index** and are presented in Figure 6. This ranking corresponds to the *rate at which countries are currently changing their position*.[8] Countries with a value of one on this index are improving their carbon productivity at the same rate at which they are experiencing increases in GDP per capita. Those countries with an index value above one are improving carbon productivity at a faster rate, while those below one are doing so at a slower rate. A negative value indicates that carbon productivity is actually falling as GDP per capita is increasing.

Germany comes top of the low carbon improvement index, ahead of a group of countries which comprises South Africa, Mexico and the United Kingdom. In Saudi Arabia and Brazil, growth in GDP is associated with a decline in carbon productivity due to emissions intensive nature of GDP per capita growth in those countries.

It is clear that performance under this measure is not simply a reflection of current wealth. Some wealthy countries, such as Germany, have recently been able to achieve high rates of carbon productivity growth as their economies have grown while others have not, such as Japan. Likewise, Mexico has been able to achieve impressive rates of carbon productivity growth as it has grown in a way that Brazil has failed to do.

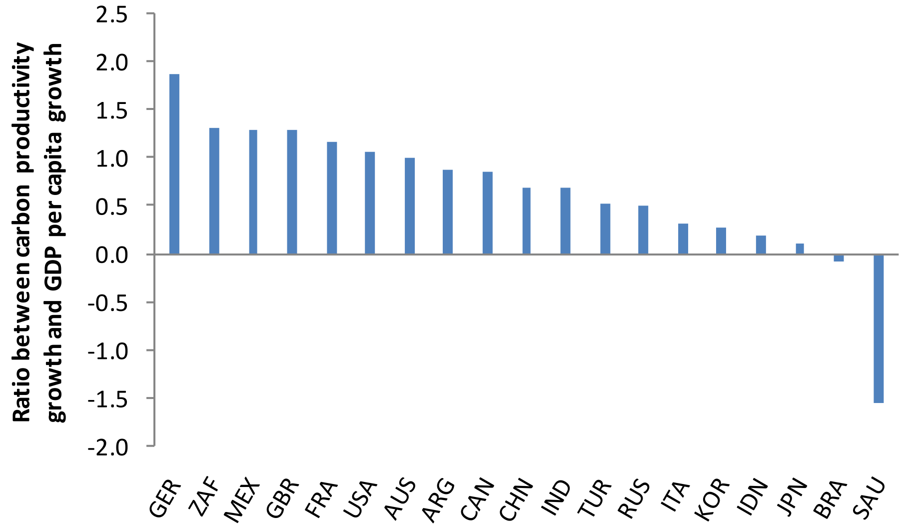
Some countries, such as Germany, France and the UK, perform well both in the low carbon competitiveness index and also in the low carbon improvement index. This indicates that these countries are already in a good position, and are continuing to improve their carbon productivity. Other countries, however, are ranked quite differently in the two indices. South Africa and Mexico are two examples of this: both countries perform better in the low carbon improvement index. Based upon their current performance on the indicators, neither country is predicted to have high levels of carbon productivity in the near term. However, the fast rate of growth in productivity, as their economies grow, suggests that these indicators are likely to be improving over time and, if the index were to be recalculated in the future, both

[7] For more details on this calculation, including standard errors, see Appendix D. As explained in more detail in the appendix, the estimates are based on econometric estimation of the relationship throughout the period. This significantly reduces the sensitivity of the results to the chosen (Kyoto protocol linked) start date.

[8] It is important to note that this is not a measure of each country's improvement in carbon productivity per se but a measure of each country's improvement in carbon productivity for a one per cent increase in GDP per capita. In other words, it is a measure of the elasticity of carbon productivity growth with respect to economic growth.

South Africa and Mexico would improve their rankings. Table 5 below shows the performance of each country in both the low carbon improvement and the low carbon competitiveness indices.

Figure 8 Germany comes top of the low carbon improvement index, but some industrialising economies also perform well



Source: Vivid Economics analysis of World Bank data

The low carbon improvement index provides encouraging evidence that nations are able to improve carbon productivity while still being able to grow their economies. The next sub-section, setting out the low carbon gap index, considers whether this rate might be sufficient to meet carbon reduction goals under some IPCC scenarios.

4.3 Further improvements in carbon productivity growth are required by most countries

The previous section analysed the rate at which the carbon productivity of the G20 economies has improved (or deteriorated) as their economies have grown (or shrunk) in the recent past. The question that this begs is how many countries are currently improving quickly enough to ensure that global targets for climate change are met given expectations of future growth.

Considering the challenge that each country faces in a comparable way is a difficult topic given the diversity of characteristics among the G20 nations. It is nonetheless important. Those economies that need to make the greatest changes to their carbon productivity in the low carbon transition will probably find the transition more difficult and costly than those

Table 5 The performance of countries across the low carbon competiveness and low carbon improvements indices varies significantly

Country	Rank in the low carbon competitiveness index	Rank in the low carbon improvement index	Country	Rank in the low carbon competitiveness index	Rank in the low carbon improvement index
France	1	5	Mexico	11	3
Japan	2	17	Russia	12	13
UK	3	4	Argentina	13	8
South Korea	4	15	Turkey	14	12
Germany	5	1	Australia	15	7
China	6	10	South Africa	16	2
Canada	7	9	India	17	11
Italy	8	14	Saudi Arabia	18	19
Brazil	9	18	Indonesia	19	16
USA	10	6			

Source: Vivid Economics analysis

that need to make less dramatic changes. They will be disadvantaged for a number of reasons.

— Not only will their volume of emissions have to be reduced, but the rate at which these reductions occur will need to accelerate. Achieving this over a shorter timeframe will result in higher adjustment costs.[9]

— This will necessitate a rapid increase in the price of carbon. This may be a rise in the explicit price of carbon in those jurisdictions with institutions creating a carbon

[9] Assuming adjustment costs are convex i.e. increasing in the magnitude of the adjustment.

price, or it may be a rise in the implicit price as regulations and pollution controls become stricter.

— An important component of these adjustment costs will be the need to retire large parts of the country's capital stock early, as the carbon constraint will make it economically unprofitable before the end of its physical life.

— Consequently, the amount of resources that need to be allocated to investment will be relatively greater than that in countries which started preparation earlier (and so have a smaller stock of obsolete capital). A greater share of national income being spent on investment will necessarily leave a smaller share available for private consumption and Government expenditure.

— As well as the obvious impacts from rapidly increasing carbon prices and relatively higher adjustment costs in economies which face a bigger challenge, the uncertainty such an environment generates may also have detrimental effects on both residents and business in a country (Dixit and Pindyck (1994)). This could result in the economy producing below its potential.

The challenge that all countries face will also be affected by the state of the international carbon markets. The scope of international carbon markets will be an important determinant of the price of abatement, particularly for those countries with higher cost domestic abatement opportunities.

To undertake the analysis of the turnaround each country needs to make on a comparable basis, a number of assumptions need to be made on required emissions reductions and GDP growth rates.

In terms of emissions reductions, the scenario considered in this report is one of long-term stabilisation of greenhouse gas concentrations in the atmosphere at 450 ppm CO_2e, allowing for a temporary overshoot. This scenario is taken from Table 5 of den Elzen and Höhne (2008) which in turn is based upon IPCC and other published scenarios.[10] Under this pathway, global emissions levels in 2020 are 25 per cent above 1990 levels. The midpoint of the range of emissions reduction for Annex I countries (as presented in den Elzen and

[10] It should be noted that there is some recent evidence which indicates that the IPCC scenarios may be too optimistic (Garnaut et al (2008)) and that the level of effort required will be much larger than implicitly assumed by the IPCC scenarios.

Höhne (2008)) that corresponds to this scenario is 32.5 per cent. In turn, this implies that total emissions growth in non-Annex I countries need to be limited to 108 per cent above 1990 levels.[11] The required emissions reductions up to 2020 are assumed to take place at a constant annual rate. All Annex I countries are assumed to have identical targets, as are all non-Annex I countries. These scenarios are outlined in Table 6.

Table 6 There are a range of scenarios associated with long term stabilisation of greenhouse gas concentrations in the atmosphere at 450 ppm

Scenario	Global growth in emissions allowed to meet target from 1990 to 2020 (%)	Annex I countries target for emissions in 2020 relative to 1990 (%)	Implied non-Annex I target for emissions in 2020 relative to 1990 (%)
Weak	+30.0	-25.0	+109.3
Midpoint	+25.0	-32.5	+107.9
Tough	+15.0	-40.0	+94.3

Source: den Elzen and Höhne (2008) and Vivid Economics calculations

GDP growth rates are actual rates from 1990 to 2005 and projections from the US Department of Agriculture from then to 2020. These projections are, in turn, based upon forecasts by Oxford Economic Forecasting, the World Bank and the IMF.

Table 7 outlines the assumptions on GDP per capita growth, and the required changes in emissions and carbon productivity that flow from these, on a country-by-country basis. The last column shows the required growth in carbon productivity that is required if the country is to meet its share of the emissions target while growing its economy as anticipated. Figure A2, in Appendix D, presents the range applicable to the calculations in this section.

This required improvement in carbon productivity can then be compared with the trajectory that each country is currently on. As this measure takes into account different targets and rates of growth for each country, it can be considered as providing a measure of 'comparable effort'. This provides the **low carbon gap index** and is shown in Figure 9. A negative value of this index implies that a country is already exceeding its implied target, while a positive value shows the amount by which its rate of carbon productivity needs to increase in order to do so. For this reason, the scale is inverted.

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[11] Using data from Table 4 of den Elzen and Höhne (2008). In the climate change literature, the usual reference made in relation to targets of non-Annex I countries is 'deviation from business as usual'. This report does not make any assumptions about business as usual for non-Annex I countries, but directly calculates the limits on emissions increases, on average, that will be required to meet the global cap for the given Annex I reductions.

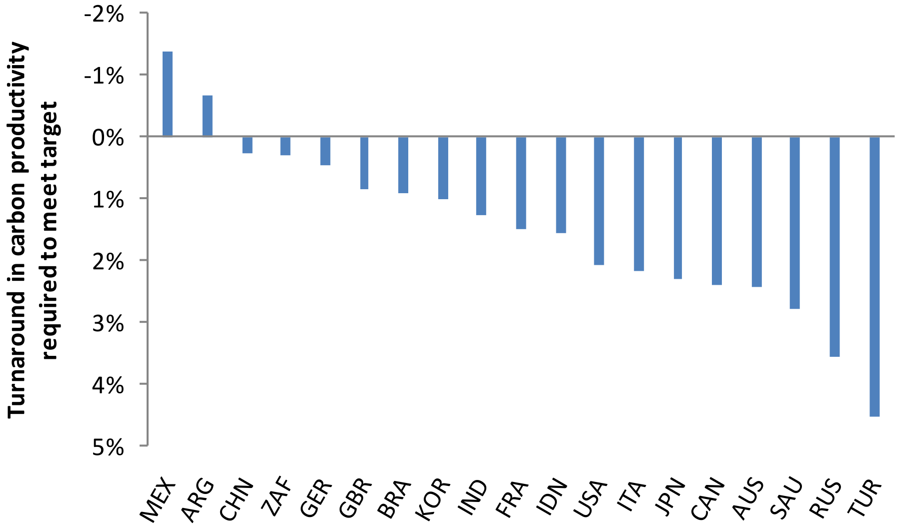
Table 7 With specific estimates of GDP growth rates, it is possible to calculate the required improvements in carbon productivity required if countries are to meet ambitious 2020 emissions targets

Country	GDP growth (1990-2020 average) (% p.a.)	Emissions growth allowed to meet target (% p.a.)	Required growth in carbon productivity (1990-2020) (% p.a.)
ARG	4.06	2.47	1.55
AUS	3.10	-1.30	4.46
BRA	3.31	2.47	0.82
CAN	2.57	-1.30	3.92
CHN	9.25	2.47	6.61
FRA	1.89	-1.30	3.13
GBR	2.24	-1.30	3.59
GER	1.68	-1.30	3.02
IDN	4.66	2.47	2.13
IND	6.73	2.47	4.15
ITA	1.22	-1.30	2.56
JPN	1.08	-1.30	2.41
KOR	4.77	2.47	2.25
MEX	3.03	2.47	0.54
RUS	2.03	-1.30	3.37
SAU	4.12	2.47	1.61
TUR	4.31	-1.30	5.68
USA	2.69	-1.30	4.04
ZAF	3.55	2.47	1.05

Source: Vivid Economics calculations

Mexico and Argentina are already doing more than is required to meet the given scenario. However, this outperformance is for different reasons. In the case of Mexico, it has one of the lowest required improvements in carbon productivity due to reasonably low anticipated GDP growth coupled with its status as a non-Annex I country and strong carbon productivity growth. Argentina's carbon productivity does not change as fast as Mexico's as the economy grows, but the higher rate of GDP growth and lower rate of population growth in Argentina means that its GDP per capita is increasing more quickly, and so more carbon productivity growth is being observed currently.

Figure 9 Only two G20 countries are currently improving carbon productivity quickly enough to meet carbon reduction targets



Source: Vivid Economics Analysis of World Bank data

The case of China is important. Its strong projected economic growth means that it needs to achieve the largest improvement in carbon productivity of all of the G20 countries. Nonetheless, it is a target that China is only just short of missing at present. If the country was to return towards the rates of carbon productivity growth seen in the 1990s (rather than that seen in the period between 2000 and 2005) then it would be able to meet its target.

Germany's performance is notable: despite being part of the Annex I grouping with a tougher emissions target, it is very nearly on track to meet its target due to its high rates of carbon productivity improvement.

The UK, Brazil and South Korea need to improve their rate of carbon productivity growth by less than one per cent to meet their implied targets. If the recent acceleration in South Korea's rate of carbon productivity growth is sustained, then this is likely to be achieved.

At the other end of the index, Turkey, Russia and Saudi Arabia face the biggest challenges to meet their targets with all three countries needing to improve their growth rate of carbon productivity by between 2.5 and 5 percentage points per annum in order to meet their targets. Canada and Australia also require a large improvement in their carbon productivity growth rate: around 2.4 percentage points.

A country's performance in the low carbon gap index reflects how its current trajectory of GDP and carbon productivity growth (or decline) compares with that which is required for it to meet the scenario set out in Table 6. A country will perform well in this index the stronger the relationship between carbon productivity and GDP growth (as given by the low carbon improvement index) and the less stringent is its target under the 450 ppm CO_2e stabilisation scenario. Consequently, compared to the low carbon improvement index, non-Annex I countries typically do better under the low carbon gap index. Past and projected growth in GDP per capita will also impact upon the turnaround in rates of carbon productivity growth that are required, but the impact is not the same across countries.

The low carbon gap index shows that some countries are already doing enough to meet an ambitious global climate change agreement. Indeed, most of the countries that are close to the required improvements are industrialising countries. While this partly reflects the fact that their emissions will be allowed to increase while those of Annex I nations have to fall, it nonetheless suggests that the allocation of a global target to industrialising nations as identified by the IPCC is not beyond their reach. Annex I countries generally have more work to do than non-Annex I countries, with no Annex I country currently on track. However, the cases of Germany and the UK offer optimism that, despite the relatively large challenge for Annex I countries, it is a goal that is achievable. However, as well as these positive conclusions, it also illustrates that there are a number of countries, including Turkey, Russia, Saudi Arabia, Australia and Canada, that are currently falling well short of the required improvement in carbon productivity and that require significant turnarounds in their performance. The longer these countries take to achieve these turnarounds, the more costly (economically, as well as socially and politically) the eventual transition will be.

5 Conclusions

This report shows that there is a wide range of performance amongst the G20 countries when it comes to low carbon competitiveness. These performances reflect different starting points and different levels of national ambition, but show that there is the potential for all countries to improve and move closer towards low carbon best practice. The low carbon competitiveness index reveals that France is currently best placed to offer prosperity to its residents in a low carbon world.

The low carbon improvement index reveals that improvements in carbon productivity need not be at the expense of economic growth, in either developed or industrialising economies. Countries as diverse as Mexico, South Africa and Germany have shown the ability to decouple their economies from emissions growth. However, this experience has not been matched by all countries of the G20. Indeed, Brazil and Saudi Arabia have increased the carbon intensity of their economies as they have grown in the period between 1990 and 2005.

Despite the progress being made by some countries, significant further progress is required if dangerous climate change is to be avoided. Only two countries of the G2O (Mexico and Argentina) are currently improving at a fast enough rate to be consistent with the 450 ppm CO_2e IPCC scenarios used in this report. Although some of the other countries may be close, they all have to increase the rate at which their economies are decarbonising. Generally speaking, Annex I countries have further to go than non-Annex I countries. There are also some countries, including Turkey, Russia, Saudi Arabia, Australia and Canada, that are currently falling well short of the required improvement in carbon productivity and that require significant turnarounds in their performance. The longer these countries take to achieve these turnarounds, the more costly (both economically, as well as socially and politically) the eventual transition will be.

Appendix A: Frequently asked questions

This appendix provides responses to some of the questions that naturally arise. Debate and feedback on the methodology are welcomed.

Why have you assumed a global carbon price when it is a distant prospect?

We don't assume a global carbon price directly but, rather, assume a global emissions constraint. We adopt this baseline because preparation for a low carbon future will require universal action, and in order to abstract from any transitory effects due to different countries regulating carbon emissions before others. This is not to suggest that such matters are not of importance to the broader debate. Issues of trade exposure, often referred to as carbon leakage, can have large impacts on the effectiveness of emissions reduction schemes and the incentives of countries or regions to adopt or strengthen them.

Why does the index focus on the carbon intensity of a nation's production rather than the carbon intensity of its consumption?

This reflects the focus of the index in understanding how the presence of global constraints on carbon emissions will affect the productive capacity and terms of trade faced by each country.

Why does the index not focus on emissions per capita?

We have not used emissions per capita as an indicator of likely prosperity or carbon competitiveness. Emissions per capita is a good measure of the contribution of an average citizen to climate change, but is not an appropriate measure of the average prosperity that a citizen will receive in an emissions constrained world, except to the extent that GDP is limited by emissions, and this is already captured in the framework of this report.

The indices take a neutral stance towards a number of further issues. They are neither intended to highlight the extent to which individual countries have contributed to the stock of greenhouse gases in the atmosphere, nor are they setting out to comment on appropriate targets on a country-by-country basis.

Some countries are going to suffer more from climatic change than others, but this does not seem to be a factor in the index?

Impacts on the economy caused by the changing climate itself are also not considered in this report, primarily for the reason that it remains difficult to accurately predict climatic changes at a sufficiently localised level and then to map those climatic changes into projected economic impacts (after sensible adaptation has occurred). This report aims to measure the progress countries are making on preparing themselves for the low carbon economy, rather than a hotter and changed climate, and to highlight the extent to which comparable action is being taken across countries.

Aren't you giving too much weight to rich countries? It seems there is no way a country with low GDP per capita can do well in the low carbon competitiveness index.

It is important to recall that the low carbon competitiveness index is not aiming to capture a country's contribution to climate change, but, rather, how well it is placed to provide future prosperity to its residents. A country's current level of wealth will be a strong determinant of its wealth in the future, and so it is to be expected that this is an important variable. The low carbon improvement index shows little systematic pattern in favour of wealthier countries and has a number of non-OECD countries near the top.

I don't understand the econometric methods you have used to arrive at the weightings, so how can I assess whether these weightings are suitable or not?

The econometrics cannot unambiguously lead to a set of uncontroversial weights. These methods have been used as a guide to minimise (but not eliminate) the subjectivity in variable selection and the relative weights given in the index. The basic idea is that the statistical techniques allow us to determine how closely a variable is related to carbon productivity, and a weighting is placed on the variable accordingly. Too literal an interpretation of the weights on each indicator should be avoided. The rankings of the countries by category are presented to allow readers to see for themselves how the index might change with different sets of weightings. While we believe our weighting selection to be reasonable, we also recognise that readers may have their own particular views on which variables are important, and we are open to conducting analyses of the data based on a different set of weightings.

I don't understand why or how you have grouped the variables into categories, which in any case seem arbitrary?

The category groupings do not significantly affect the methodology or results. The categories are used as a way to help explain the drivers of each country's ranking in the final index. We allow a statistical analysis to guide the weightings that should be given to each category.

How confident are you in the quality of the data you have used?

It is difficult to assemble data on a large range of relevant variables across such a diverse set of countries. Only sources where data for a particular variable is presented for all countries are used in order to minimise any error. Moreover, only data obtained from well-respected organisations have been used. Nonetheless, it is impossible to eliminate measurement error. However, unless it is systematically linked across the variables chosen, it will not affect a country's ranking.

Don't we already have enough indices ranking countries' environmental performance?

The need for an index dealing specifically with climate change preparedness has already been raised in the field of international comparisons of environmental performance. The Environmental Sustainability Index (ESI) of the Yale Center for Environmental Law and Policy (Esty et al (2005)) has been criticised for, among other issues, not addressing the issue of climate change sufficiently (Morse and Fraser (2005)). Furthermore, the authors of that index have noted that there is an important role for an alternative index dealing specifically with this aspect of sustainability. The indices presented in this report fill this gap with a particular focus on combining climate change preparedness with economic prosperity. In any case, this report is not solely focused on the presentation of indices – a major motivation is a desire to expand the boundaries of debate and provide new conceptual frameworks for thinking about climate change action.

Appendix B: Further details on econometric estimation

This appendix provides more detail on the econometric estimation underpinning the low carbon competitiveness index.

Data preparation

While every effort was made to keep imputation of data points to a minimum, it was not possible to construct a complete data set for all variables across all countries and years. The assumptions that were made in the construction of the data are presented in this section. Decisions made about missing data are not presented for variables which were not included in the index.

Data for greenhouse gas emissions for the six gases identified in the Kyoto protocol were obtained from the CAIT database of the World Resources Institute. Data for CO_2 emissions are available on an annual basis for all countries from 1990, while those for methane, nitrous oxide and fluorinated gases are only estimated every five years. In order to incorporate these latter sources of emissions, it was assumed that each country's emissions changed at a constant rate between the years for which data was available. Land use change and forestry sector emissions were not included for the practical and methodological reasons that result in them, for example, not being included in many IPCC scenarios and studies in the climate change literature (den Elzen and Höhne (2008)).

New Energy Finance data on private sector investment in sustainable energy was only available for the period 2005 to 2007. It was assumed that the level of investment in that period was a reflection of investment over the entire period. This approach was taken for other variables for which a time series was not available. The estimates of the balance of emissions embodied in trade were only available for a single year, for example.

Each indicator was transformed so that it had a minimum of zero and a maximum of one and that higher levels of the indicator would be expected to have a positive impact upon carbon productivity.

The calculation of the low carbon competitiveness index following this process was done using data from 2005 - the most recent year for which comprehensive data was available.

Selection of variables and weights for the low carbon competitiveness index

A backwards stepwise ordinary least squares regression with each indicator included was used to ascertain which of these variables had the strongest links to the dependent variable; that is, carbon productivity as measured by GDP per tonne of carbon. A variable was excluded from the analysis at an exclusion threshold of p=0.2.

Selecting variables for an econometric analysis is not straightforward, and many economists have noted the difficulties involved and proposed various solutions (Leamer (1983), Sala-i-Martin (1997), Hendry and Krolzig (2004)). A relatively simple approach was adopted in this report for two reasons. First, data on many variables pertinent to climate change have only begun to be measured relatively recently, particularly for developing countries, and so this limits the number of observations and, therefore, the reliability of more sophisticated techniques. Second, the variables in the index are selected on the basis that they provide a proxy for the level of GDP per tonne of carbon. This eliminates the need to be concerned about causation, which is the focus of some of the critiques of stepwise regression as used in this report (e.g. Hendry and Krolzig (2004)).

The coefficients on each indicator from the econometric estimation give an indication of the relative importance of each variable. Rather than using these weights directly, these were used to ascribe weights to each category. Indicators were then weighted equally within their category.

An alternative approach would be to dispense with the categories and weight each indicator according to this estimated weight. This approach was not pursued as it would be unwise to prescribe excessive accuracy to these individual numbers: many of the variables will be correlated with each other which will reduce the accuracy with which the coefficients are measured. Again, because causation is not critical for the purposes of this index, this is less of a concern in this application than in other contexts.

Table A1 provides a list of the indicators that were excluded from the low carbon competitiveness index as a result of this process.

Table A1 A number of variables were excluded from the index following the econometric analysis

Variable	Definition	Source	Category
Road sector fuel consumption	Litres per capita	WDI	Adjustment Costs
Researchers in R&D	Per million head of population	WDI	Adjustment Costs
Requirement for air conditioning	Number of cooling degree days	World Resources Institute	Adjustment Costs
R&D expenditure	% of GDP	WDI	Adjustment Costs
Air passengers carried	Number	WDI	Adjustment Costs
Rigidity of employment index	Scale of 0 to 100 where 0 is less rigid	WDI	Adjustment Costs
Institution rankings	Scale of 0 to 10 where 10 is most effective institutions	World Economic Forum	Adjustment Costs
Motivation of residents for action	Percentage of the population saying climate change is a very serious problem	Pew Global Centre	Adjustment Costs
Motivation of Government for action	% of recent stimulus packages spent on green measures	Edenhofer and Stern (2009)	Adjustment Costs
Price of unleaded fuel	$US/litre	GTZ	Early Preparation
New sustainable energy investment	$US equivalent by company nationality	New Energy Finance	Early Preparation
Efficiency of coal fired electricity generation	Ratio of output to input in '000 toe	IEA	Early Preparation
Carbon productivity growth	See section 2	Vivid Economics calculations	Early Preparation
Stock of forests	Square kilometres	WDI	Sectoral Composition
Use of rail	Ratio of rail to road network length	WDI	Sectoral Composition
Fossil fuel exports	Share of fuels in total exports	WDI	Sectoral Composition
Renewable energy exports	'000 toe per capita	IEA	Sectoral Composition

Source: Vivid Economics

Appendix C: Productivity measures in a low carbon world

This appendix provides a conceptual background on productivity measurement and the relationship between standard measures of productivity and carbon productivity.

Productivity is a term which is used relatively frequently in public policy debates, however, its precise meaning is seldom defined. At a very general level productivity can be thought of as the ratio of output to inputs in production, where inputs consist of such things as labour, capital and natural resources. If a country is able to produce more output without increasing the amount of inputs used, then it will have experienced a productivity gain. In this section, traditional measures of productivity are discussed in the context of emissions reductions and a transition to a low carbon economy.

Productivity measurement

In economics, the economy at the country level is often modelled by an aggregate production function. A production function is a mathematical relationship which relates output to inputs. There are two different, but related, measures of output in economics. The first is known as gross output, and is the total value of things which are produced in the economy. The second measure, and that which is used to calculate GDP, is known as value added and is calculated by subtracting the total purchases of intermediate inputs, such as raw materials, from the value of gross output. Value added represents the amount of wealth available for distribution to workers and the owners of firms.

While there is some debate about which measures are more appropriate for use both at the level of an individual firm, it is most common to use value added measures at the level of a country (Baptist (2009)). This is to avoid double counting of intermediate goods; that is, goods which are not consumed directly but are used as inputs in the production of further products.

The value added production function for a particular country can be written as

$$Y - M = AK^{\alpha}L^{1-\alpha} \qquad \text{(Equation 1)}$$

where Y represents the value of gross output, M the value of raw materials and intermediate inputs, K the value of the capital stock and L the number of hours worked by employees. The parameter α can be said to represent the technology used and is often assumed to be equal to one-third (Hall and Jones (1999)). The parameter A determines how much output can be achieved for a given amount of capital and labour. It is known as total factor productivity, and is the way in which the conceptual definition of productivity as the ratio of inputs to outputs can be quantitatively expressed.

As can be seen from Equation 1, productivity is not synonymous with gross output or value added. For example, if two countries were producing the same level of value added but one had a higher capital stock than another, then the country with more capital would have a lower level of measured productivity, as it required more inputs to produce the same level of output.

Emissions reductions are often associated with improved productivity

Purchases of fossil fuels, either for direct use or in the production of electricity, and of carbonates, which result in industrial process emissions, will typically be considered as intermediate inputs and so subtracted off the value of gross output to calculate value added. Improvements in the efficiency with which these inputs are used will therefore result in a productivity gain. This can be seen quantitatively by considering Equation 1. If a country is able to produce the same quantity of gross output with fewer intermediate inputs, then the measure of value added will increase. If the quantity of capital and labour is held constant, this in turn will result in productivity, as measured by total factor productivity, increasing.

Some low cost greenhouse gas abatement options will have this effect, such as energy efficiency measures, but the calculation is not always so straightforward. To the extent that an abatement option involves some increased use of capital and labour, the increase in the measure of productivity as calculated by Equation 1 will be mitigated.

Countries with high carbon productivity are often those with high levels of GDP per capita

The amount of GDP per capita is often used as a proxy for productivity because it can be interpreted easily by those who are not familiar with the framework set out above and because it is consistent with data collected by national statistics offices. GDP per capita is analogous to the amount of value added per worker, with the difference that the latter measure only includes workers rather than the whole population. GDP per capita will therefore only be an accurate measure of total factor productivity to the extent that the amount of capital per worker is the same across all countries. However, it is a proxy which has a firm theoretical relationship with productivity. The discussion in Section 2 regarding the potential inaccuracies in using GDP per capita as a proxy for overall prosperity or welfare should also be considered in this context.

As shown in Figure 5 of the main report there is a strong relationship between productivity, as represented by GDP per capita, and GDP per unit of emissions. This empirical evidence supports the theoretical argument above that an emissions-efficient economy can also be one which is highly successful using standard measures of wealth and productivity.

Appendix D: Calculation of carbon efficiency of growth

This appendix provides more details on the calculation of the low carbon improvement and low carbon gap indices.

Low carbon improvement index

Figure A1, below, is identical to Figure 9, but presented on a logarithmic scale. As well as having the advantage of showing more detail amongst those countries with low levels of GDP per capita, a logarithmic transformation also allows for easy calculation of the trajectory of carbon productivity growth. The following equation gives this relationship:

$$\frac{\partial \ln(GDP/GHG)}{\partial \ln(GDP/capita)} = \frac{\partial\,(GDP/GHG)}{\partial\,(GDP/capita)} \cdot \frac{\frac{GDP}{capita}}{\frac{GDP}{GHG}} = \frac{\%\ growth\ in\ carbon\ productivity}{\%\ growth\ in\ GDP\ per\ capita}$$

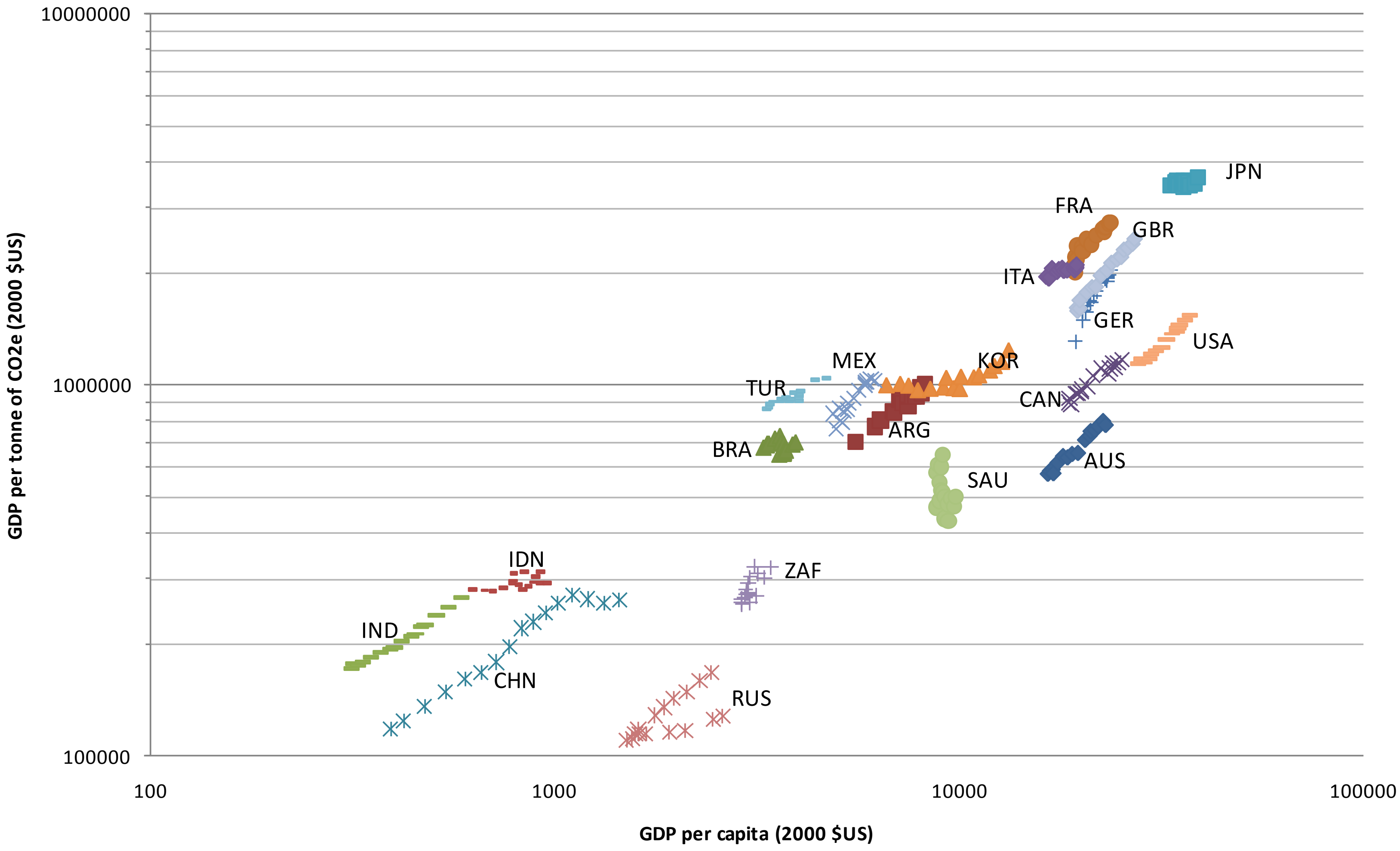
GHG refers to the volume of emissions. Thus the rate of growth of carbon productivity can be given by the growth rate in GDP per capita multiplied by the estimate of the country-specific slope coefficients β_i in the following equation:

$$\ln({}^{GDP}/_{GHG})_{i,t} = \alpha_i + \beta_i \ln({}^{GDP}/_{capita})_{i,t} + u_{i,t}$$

Where $u_{i,t}$ is an error term and the subscripts i and t refer to countries and years respectively. An alternative way to calculate this growth rate, rather than estimating it based upon the past observed relationships, would be simply to calculate the empirical growth rate between 1990 and 2005. This approach was not pursued, however, because it makes the results highly sensitive to the initial conditions, that is, the level of carbon productivity and GDP per capita in 1990. For some countries, notably Russia and South Africa, 1990 was an atypical year and so using this as a baseline would introduce unacceptable error.

The estimation process also explicitly recognises that these variables are measured with error and the relationship is not perfectly deterministic, and so enables the calculation of standard errors in order to assess the robustness of the results. These are presented in Table A2.

Figure A1 Carbon productivity and GDP per capita on a logarithmic scale



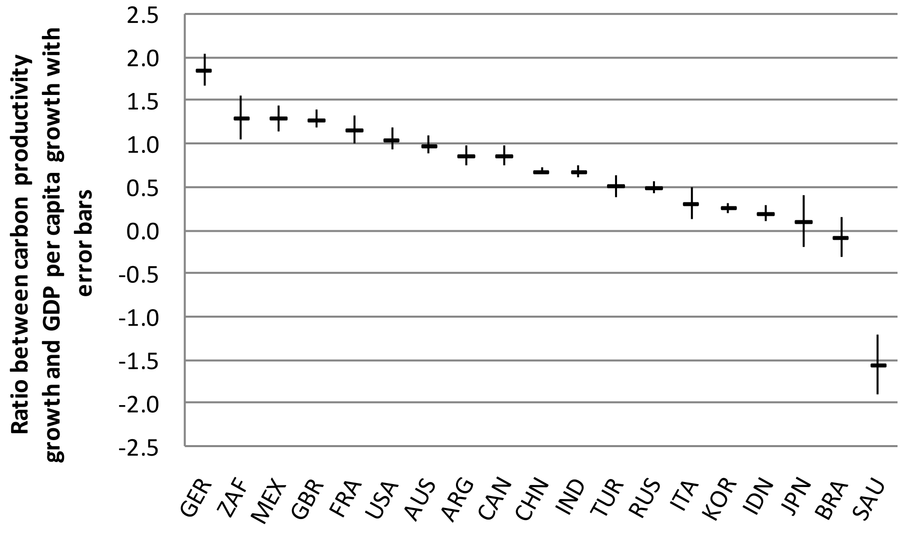
Source: Vivid Economics calculations from World Bank data

Table A2 Standard error of the estimate of current trajectory of carbon productivity improvements, by country

Country	Elasticity of carbon productivity w.r.t. GDP per capita (% p.a.)	Standard error of estimate	Number of observations used in estimation
ARG	0.87	0.11	16
AUS	0.99	0.10	16
BRA	-0.08	0.22	16
CAN	0.86	0.11	16
CHN	0.69	0.03	16
FRA	1.17	0.15	16
GBR	1.29	0.10	16
GER	1.87	0.18	16
IDN	0.19	0.10	16
IND	0.68	0.06	16
ITA	0.31	0.18	16
JPN	0.11	0.29	16
KOR	0.26	0.06	16
MEX	1.30	0.16	16
RUS	0.50	0.07	16
SAU	-1.55	0.35	16
TUR	0.51	0.12	16
USA	1.06	0.12	16
ZAF	1.31	0.26	16

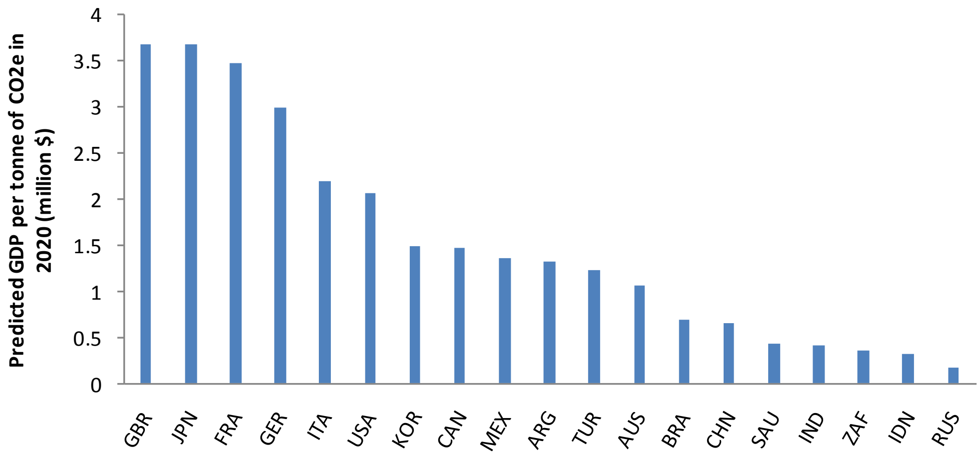
Source: Vivid Economics calculations

Figure A2 Range estimates for the low carbon improvement index



Source: Vivid Economics calculations

Figure A3 The United Kingdom is on course to have the highest rate of carbon productivity by 2020



Source: Vivid Economics

The percentage change in carbon productivity expected if GDP per capita increased by one per cent, the elasticity of carbon productivity growth with respect to GDP per capita, is calculated by estimating the country-specific slope coefficient in the above equation. The estimates and standard errors from these calculations are presented in Figure A2. The standard errors indicate, for example, that there is more uncertainty surrounding South Africa's true elasticity than India's. In South Africa's case, the higher uncertainty is due to a much narrower range of GDP per capita being observed over the period along with high volatility in carbon productivity

Assuming that (the best estimates of) countries' recent changes in carbon productivity persist in the future and coupling this information with expected GDP growth rates allows an alternative way to consider how well countries will be placed to generate material prosperity in a carbon constrained future, as measured by their level of GDP per tonne of CO_2e. This analysis is presented in Figure A3, where 2005 emissions are projected forward to 2020 using the results of the low carbon improvement calculations. The United Kingdom will, if these growth rates are maintained, have overtaken Japan in terms of how much GDP it can produce per tonne of CO_2e, while France and Germany will not be far behind. These are the same three European countries that also performed well in the low carbon competitiveness index.

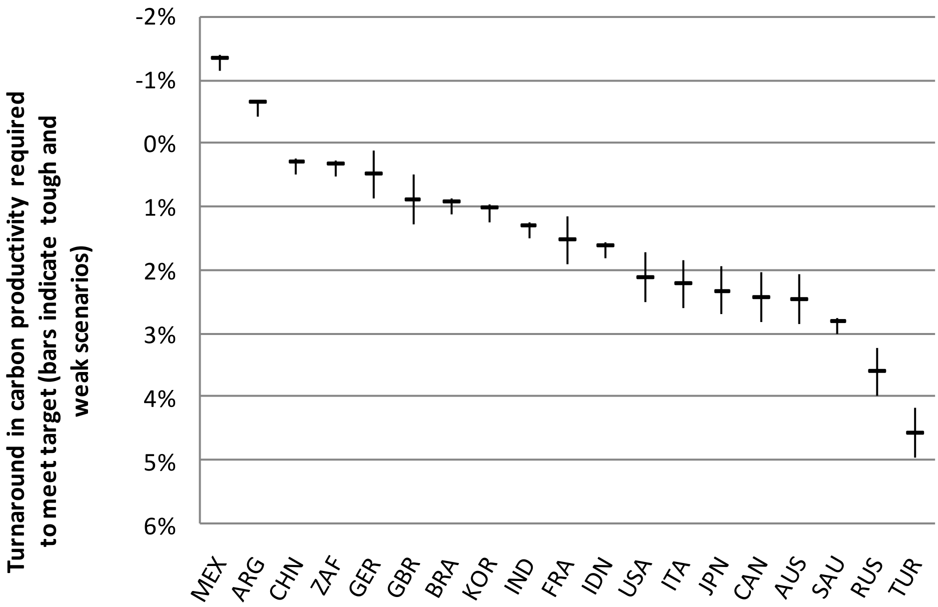
Low carbon gap index

The calculations of the turnaround required are based upon a comparison between the rates of improvement in carbon productivity being observed now with those that would be required to meet a particular IPCC scenario and a set of forecasts of GDP growth. The IPCC scenario chosen, stabilisation at 450 ppm CO_2e with a temporary overshoot, encompasses ranges of uncertainty. IPCC Box 13.7 gives Annex I countries a target of between -25 and -40 per cent, while den Elzen and Höhne (2008) conclude that global emissions growth from 1990 to 2020 must be limited to between +15 and +30 per cent to meet this same target. The main calculations took targets of -32.5 and +25 per cent, respectively, but there is some uncertainty surrounding these. In order to account for this, a similar calculation was made under both a weak and a tough scenario. Under the weak scenario, total global emissions growth is allowed to be 30 per cent and Annex I countries are set a target of -25 per cent; under the tough scenario the targets are +15 and -40 per cent respectively. Required turnarounds are higher in the tough scenario and lower in the weak scenario. Note that the midpoint of required global emissions in 2020 is not the arithmetic mean of 15 and 30, rather it is the average estimate from the relevant studies.

Figure A4 plots the turnaround required under the scenario chosen in the text, and the bars either side of this represent the range of turnaround that would be required under both the weak and the tough scenario. The range of turnaround required is much greater for Annex I countries than it is for non-Annex I countries. This is because the range for the Annex I targets given in den Elzen and Höhne (2008) is almost sufficient to account for the change in total global emissions that are required between the tough, midpoint and weak scenarios.

The ranking of countries remains fairly stable between the three scenarios. Compared to the midpoint scenario, the only changes in the weak scenario are that Germany and France each overtake the country that is immediately ahead of them in the midpoint scenario (South Africa and India respectively). Conversely, in the tough scenario the changes are that the UK falls behind the two countries that are immediately below it in the midpoint scenario (Brazil and South Korea), while France falls behind Indonesia.

Figure A4 Range estimates for low carbon gap index



Source: Vivid Economics calculations

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