Prosperous living for the world in 2050:
insights from the Global Calculator

Overview

By 2050, the global population is expected to grow from 7 billion today to 10 billion, and the global economy is expected to triple in size[1]. But by 2050, the world needs to cut harmful greenhouse gas emissions to around half of today's levels to have a chance of meeting our international commitments to constrain the global mean temperature increase to 2°C. Is it physically possible to meet our climate targets and ensure everyone has good living standards by 2050?

"Is it physically possible to meet our climate targets and ensure everyone has good living standards by 2050?"

To answer this question, experts from over ten leading international organisations came together to build a model of the world's energy, land, food and climate systems to 2050. The team built the "Global Calculator" to model what lifestyle is physically possible for the world's population – from kilometres travelled per person to calorie consumption and diet – and the energy, materials and land requirements to satisfy all this. The climate impacts of different pathways are also illustrated by linking the model to the latest Intergovernmental Panel on Climate Change (IPCC) climate science. The model has been tested with experts from more than 150 organisations around the world. Uniquely, you can use it yourself – the model, its methodology and assumptions are all published (see www.globalcalculator.org).

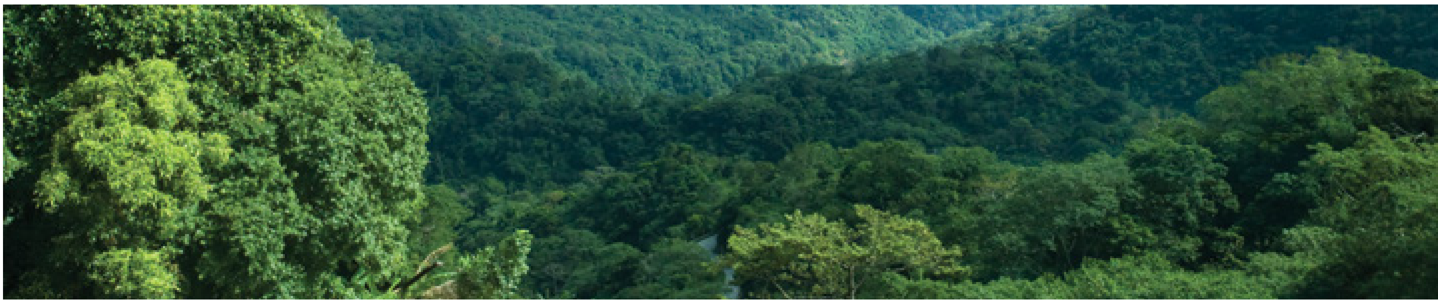
The Global Calculator tool shows that there are many different pathways to 2°C. The team generated four plausible pathways to 2°C that enable good lifestyles, and explore the key uncertainties about technology, fuels and land use. These four plausible 2°C pathways show that:

- Yes, it is physically possible that all 10 billion people in the world could eat well, travel more and live in more comfortable homes, whilst at the same time reducing emissions to a level consistent with a 50% chance of 2°C warming.

- But to do so, we need to transform the technologies and fuels we use. For example, the amount of CO_2 emitted per unit of electricity globally needs to fall by at least 90% by 2050. Also, the proportion of households that heat their homes using electric or zero-carbon sources should rise from 5% today to 25-50% globally by 2050.

- We also need to make smarter use of our limited land resources. In particular, we must protect and expand our forests globally by around 5-15% by 2050 because forests act as a valuable carbon sink.

1 Global GDP is $67 trillion in 2011, projected to rise to $200 trillion in 2050 (OECD, 2014; Economic Outlook no. 95, May 2014, Long Term Baseline Projections. Potential output of total economy, volume [PPP prices]. Available at http://stats.oecd.org)



The Global Calculator has only limited geographical detail, so it cannot give details of which countries the technologies should be rolled out in or who should pay for them. It also only models average consumption per person globally[2], rather than according to country. So although the tool shows that global average diet, transport use and household appliance use can rise to levels consistent with a good lifestyle by 2050, it does not specify how this consumption should be distributed by country (for example, whether the richest should reduce their consumption). These are questions of a political nature and beyond the scope of the Global Calculator.

"The world has enough energy, land and food resources for us all to live well."

However, the Global Calculator does unequivocally demonstrate that it is physically possible to achieve both our economic development and climate change goals by 2050. The world has enough energy, land and food resources for us all to live well. The technology, fuels and land use methods already exist for us to meet our economic development goals, whilst tackling climate change.

But making this transition to low carbon will require a massive effort across all sectors and action must start urgently. We need to ramp up the take up of clean technologies across the electricity, buildings, transport and manufacturing sectors and significant improvement in our land management practices. And 2050 is not the end of the journey: our technological and land management reforms must extend throughout the rest of the century such that the world has around zero net greenhouse gas emissions by 2100 to be on track for our 2°C target.

To ensure that these changes are rolled out, strong leadership from businesses, civil society and politicians is essential to support urgent action to cut emissions through an ambitious global deal in the December 2015 United Nations Framework Convention on Climate Change (UNFCCC) negotiations.

2 Food consumption is calculated based on global averages. Travel behaviour is segmented according to the type of area the journey is undertaken in (rural developed, rural developing, international, urban automobile, urban transit or urban booming city). Energy use in buildings is disaggregated by: urban with access to electricity, urban without access to electricity, rural with access to electricity and rural without access to electricity.

Detailed findings

"We could even travel further: average distance per person increasing from 8,300 km/head today to 12,400 km/head in 2050."

Lifestyle

The tool finds that we can achieve our 2°C target while providing more households with access to electricity (94% in 2050[3], compared to 84% today[4]). Our homes could be more comfortably heated and cooled (e.g. the average indoor winter temperature could rise from 16°C today to 19°C by 2050, and the average indoor summer temperature could fall from 27°C today to 24°C by 2050). We could also own more appliances (e.g. from an average 0.8 washing machines per urban household today to one in every urban household by 2050).

We could even travel further: average distance per person increasing from 8,300 km/head today to 12,400 km/head in 2050. This includes a 400 km per person increase in distance travelled by air between now and 2050 (equivalent to a flight from London to Amsterdam). The proportion of distance travelled by car could increase slightly from 37% today to 40-45% in 2050.

We have enough land to ensure that everyone has enough to eat: 2,180 calories per head today, rising to 2,330 calories per head in 2050 (above the WHO's recommended level of 2100 calories per head per day, which is required for an active and health lifestyle).

What is a "good" lifestyle?

The four plausible 2°C pathways set out in this report have lifestyle indicators that approximately match a business as usual scenario[5] where lifestyles continue to improve as economies develop. By comparing these indicators to historical trends and different countries today, you can see that global average consumption moves towards the current levels seen in developed countries such as those in Europe. As the Global Calculator looks at world averages only, this could mean that inequality has reduced by 2050 with more people living close to the average lifestyle, or it could still mean that there is a lot of variation between countries as seen today (for example with overconsumption of food in some areas).

3 Unless otherwise stated, all figures in this paper are calculated based on the range from the four plausible 2°C example pathways: distributed effort, consumer reluctance, low action on forests and consumer activism. These are in the tool: http://tool.globalcalculator.org

4 The model uses data from the year 2011 as a baseline. As the most recent data available, it is referred to in this report as today.

5 Throughout this paper, business as usual is defined as the Global Calculator example pathway, "IEA 6DS (approximate)". This assumes current policies only.

Figure 1: In our four plausible 2°C pathways, global average domestic travel increases between 2011 and 2050 from 7,500 to 11,000 km per person per year[i ii]

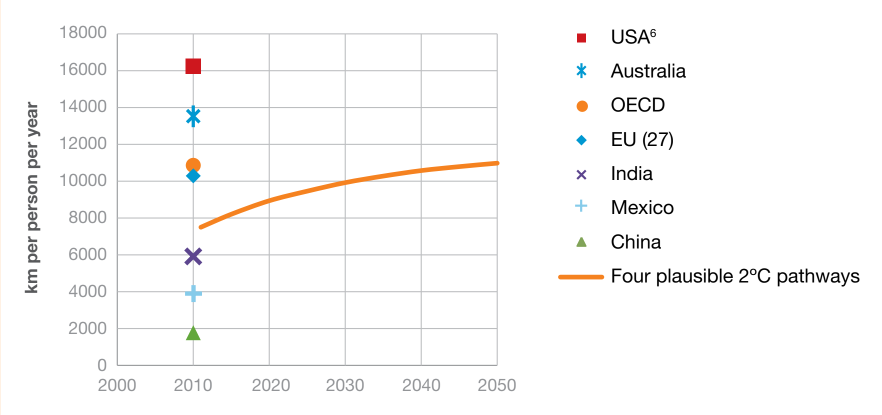


Figure 2: In our four plausible 2°C pathways, average urban home temperatures increases between 2011 and 2050 from 17.5 to 19.9° C

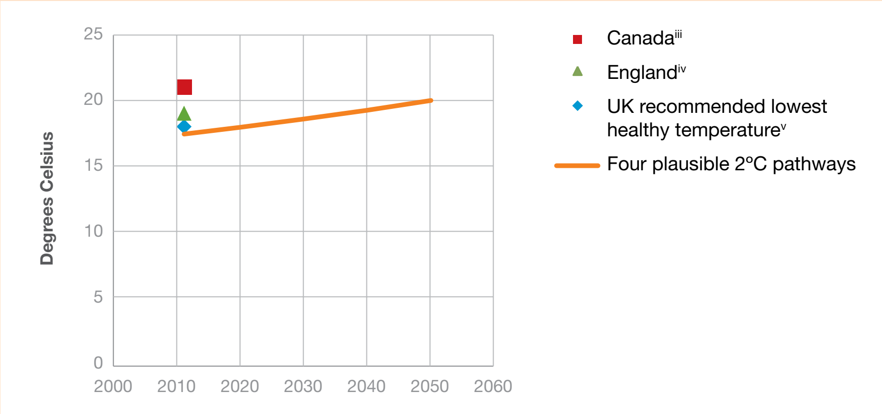
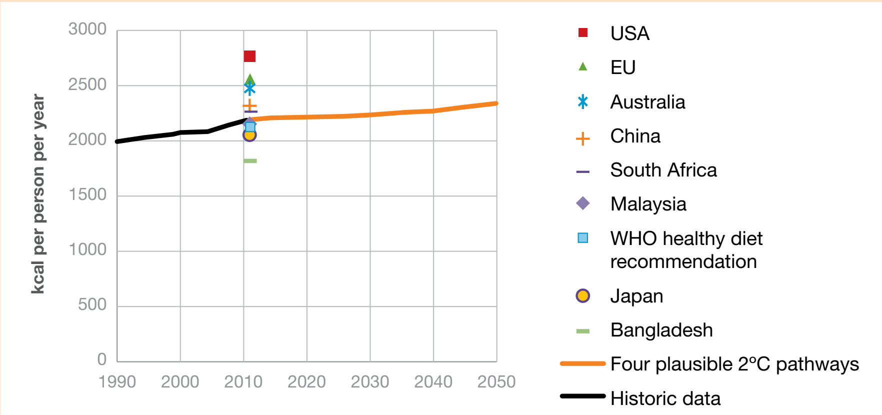


Figure 3: In our four plausible 2°C pathways, global average calorie consumption increases between 2011 and 2050, from 2,180 to 2,330 kcal per person per year



6 In the four scenarios, distance per head in 2050 roughly corresponds to EU/OECD average. Today, some countries like the USA and Australia have much higher distance per head than this, but these are large countries with small population densities. This amount of domestic travel is not needed in smaller, denser countries, so is unlikely to become the world average.

Technologies and fuels

The growth in global population and average consumption per head will lead to big increases in global energy demand. Under a business as usual scenario (with the same lifestyle standards described above), energy demand would increase by around 70% between now and 2050. However, in the four 2°C pathways set out in this report, the same lifestyle standards could be achieved with at most a 25% increase in global energy demand by 2050.

This restraint in energy demand is largely due to the considerable role for energy efficiency. Buildings in 2050 must be 50-65% better insulated and our appliances should be more efficient than today (for example, refrigerators should be 40% more efficient). Cars should be around 50% more efficient. Manufacturers of goods such as cars and washing machines could reduce the energy used in the production of these products by up to 25% by 2050 through smarter product design[7]. Manufacturers of raw materials could also save energy: for example, the chemicals sector could reduce its energy use by up to around 10% through greater energy efficiency and fuel switching[8].

There is also an important role for technology switch. For example, 25-50% of the energy used to heat our homes globally should come from electricity or zero-carbon sources such as heat pumps or solar thermal. Up to 35% of our cars should be electric or hydrogen by 2050.

"The biggest potential sources of electricity generation will be solar, wind, hydro, nuclear and carbon capture and storage."

Substitution away from fossil fuels is also critical. Fossil fuel use must fall from 82% of our primary energy supply today to around 40% by 2050. In particular, coal demand must fall from around 160 EJ today to 45-60 EJ in 2050. This means that we need to have left at least 35-50% of current oil reserves, 50% of gas reserves, and 80-85% of coal reserves in the ground in 2050.

Changes in the way we power our technologies will require the global supply of electricity to almost double from 2011 levels by 2050. This needs to be met by largely decarbonised electricity, with the amount of CO_2 emitted per unit of electricity globally falling by at least 90% by 2050. The biggest potential sources of electricity generation will be solar, wind, hydro, nuclear and carbon capture and storage (CCS), and we need very ambitious effort on at least two of these. We will still need some fossil fuel electricity generation (for example, for electricity balancing) but it must be cleaned up. We need to move away from unabated coal power plants with immediate effect and install CCS on 500 to 1,500 GW of our fossil fuel generation capacity by 2050 (equivalent to around 700 to 2,100 power plants).

7 Total energy demand for manufacturing falls by 25% when the business as usual pathway (IEA 6DS) has its "design, materials and recycling" lever set at level 3 (this is the most ambitious lever setting among the four plausible 2°C pathways).

8 Energy demand for chemicals falls by 7% when the business as usual pathway (IEA 6DS) has its "chemicals" lever set at 3 (this is the most ambitious lever setting among the four plausible 2°C pathways).

How challenging will it be to clean up our technologies and fuels?

To get a better sense of how challenging it will be to clean up our technologies and fuels, we can compare the changes required with historical trends.

"In our pathways, the global average carbon intensity of electricity generation reduces to near zero by 2050."

Figure 4: In our four plausible 2°C pathways, the global average carbon intensity of electricity generation reduces to near zero by 2050[9]

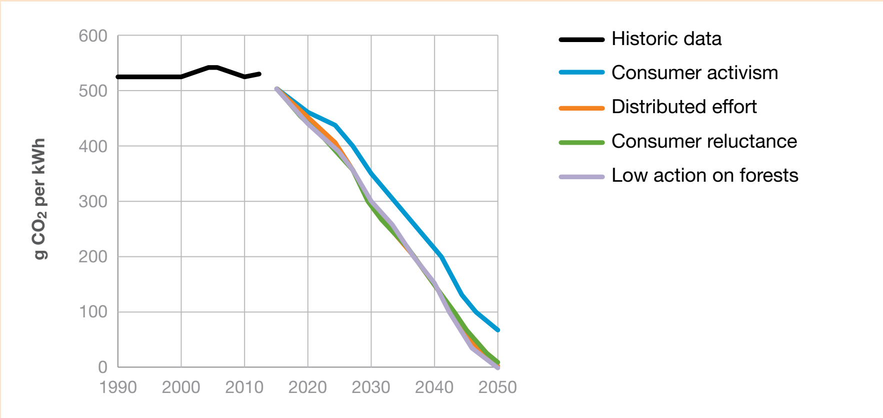
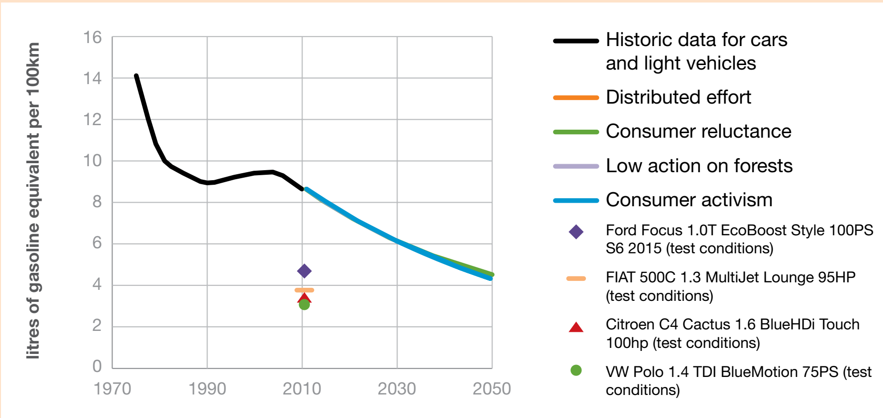
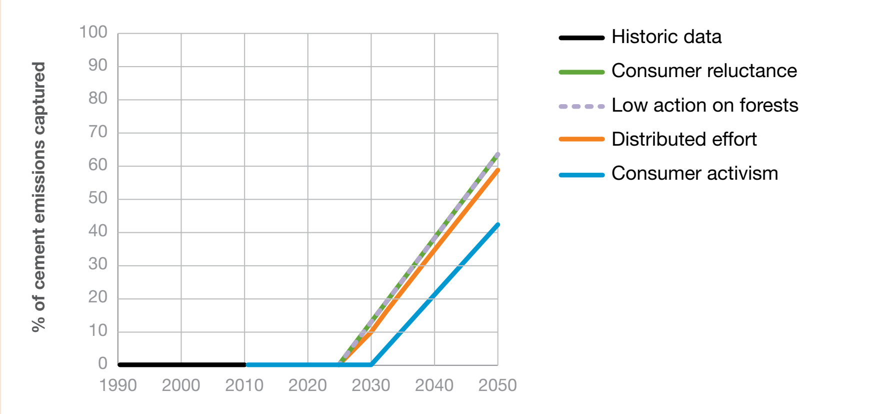


Figure 5: In our four plausible 2°C pathways, the global average fuel consumption of passenger cars reduces between 2011 and 2050, from 8.6 to 4.3-4.5 litres of gasoline equivalent per 100 km[vi]



9 Carbon intensity of electricity generation data for 1990 to 2010 is from IEA 2014 publication: CO_2 Emissions from Fuel Combustion.

Figure 6: In our four plausible 2°C pathways, up to 64% of emissions from the manufacture of cement would need to be captured by 2050, compared to zero in 2011



"We should be expanding our forest area by 5-15% by 2050 because forests act as carbon sinks."

Land

Cleaning up our energy system is part of the solution, but not all of it. Over the last 10 years, almost 200 million hectares of native forest land has been cut down, partly driven by increased demand for agricultural land. Total demand for food could rise by around 45% by 2050[10] as population and wealth increase, so this deforestation trend is at risk of continuing. But to protect our climate, we should be expanding our forest area by 5-15% by 2050 because forests act as carbon sinks (i.e. they actually remove carbon dioxide from the atmosphere and store it as carbon in the trees and soil). To achieve this, we must use our agricultural land more productively.

In particular, we need to focus on livestock management and production. For example, we need the proportion of beef produced from confined systems (6% today) to be between 3% and 15% by 2050. Also, for cows fed on pasture land, we need to increase the average number of cows per hectare (100 m x 100 m) from 0.6 today to 0.9-1.0 by 2050. Crop yields should also be 40-60% higher than 2011 levels by 2050. There is also scope to further increase productivity by making multiple uses of land (e.g. co-cropping or multi-cropping), which is needed to reduce the land required for crops by around a further 10%.

Switching away from beef consumption, towards more poultry, pork, vegetables and grains can also significantly reduce the amount of land required to produce food. For example, currently an area the size of a football pitch can be used to produce 250 kg of beef, 1,000 kg of poultry (both fed on grains and residues) or 15,000 kg of fruit and vegetables.

10 Assumes average calorie consumption per person rises from 2,180 kcal in 2011 to 2,330 kcal in 2050 (level 2) and population rises to 9.6 billion in 2050 (level 2).

Decreasing the amount of meat in the global average diet would also have benefits for our climate and human health. In 2050, if everyone switched to the healthy diet as recommended by the World Health Organisation (2,100 calories on average, of which 160 calories is meat), this could save up to 15 $GtCO_2e$ in 2050[11] as the freed up land is used for forest or bioenergy. This carbon saving could be comparable in scale to around a third of total global CO_2 emissions in 2011.

There is a potential conflict for use of land for food or bioenergy. But this is not inevitable: smart use of our land could ensure we can protect or even expand our forests, produce all the food we need, and increase land for bioenergy from 98 million hectares today to up to 350 million hectares by 2050. This bioenergy could account for 15-20% of our primary energy by 2050.

"Crop yields need to be increased by 40-60% between 2011 and 2050."

How ambitious are these changes in land use?

To get a better sense of how ambitious these land use changes are, we can look at the historical trend in key metrics for this sector.

Figure 7: In our four plausible 2°C pathways, crop yields need to be increased by 40-60% between 2011 and 2050

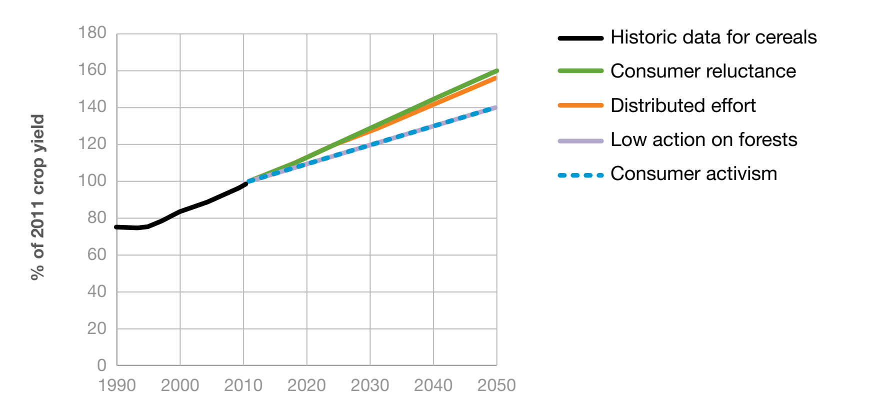
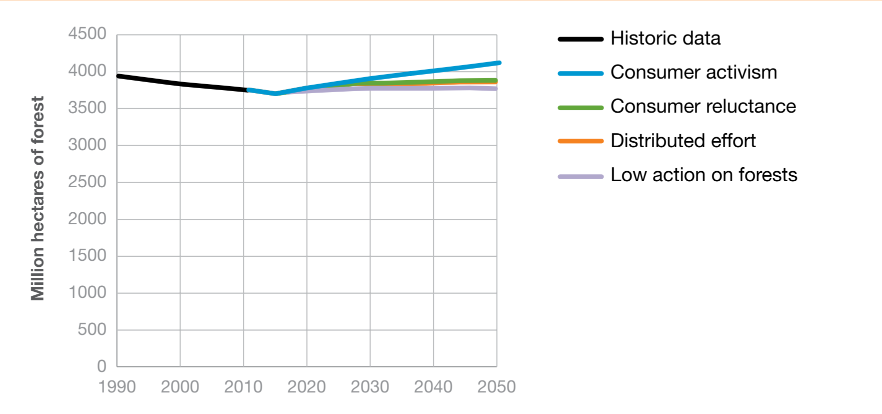


Figure 8: In our four plausible 2°C pathways, the global area of native forests should be increased by 25-360 million hectares between 2011 and 2050



11 Calculated using the "consumer reluctance" pathway and comparing this with WHO healthy levels (levels 4 for calories consumed and 3 for meat consumed).

"The total cost of a decarbonised energy system is only fractionally higher than one that stays fossil fuel dependent, and it could even be cheaper."

Costs

The Global Calculator estimates the total capital, operating and fuel cost of the global energy system out to 2050. For example, it includes the costs of building and maintaining power stations, wind turbines, heat pumps, boilers, cars, trains, planes, roads, railways and the clean technology used in manufacturing, as well as the fuels, such as fossil fuels and bioenergy, used to power these technologies.

Under business as usual, the total energy system cost could more than double between 2011 and 2050. This reflects the growth in vehicle and appliance ownership associated with a growing, wealthier global population, and a 70% increase in global energy demand. However, the total cost of a decarbonised energy system is only fractionally higher than one that stays fossil fuel dependent, and it could even be cheaper. For example, the 2°C pathways outlined in this paper range from saving 2% of global GDP compared to business as usual, to being more expensive by 3% of global GDP[12]. This does not take into account wider economic benefits from switching to a 2°C pathway, in particular the fact that under business as usual the world would experience more floods, droughts, heat waves and crop failures.

There are a variety of reasons why the energy system cost of 2°C pathways could be more or less expensive than business as usual. On the one hand, 2°C pathways can be more expensive because the capital costs of clean technologies tend to be greater than the fossil fuel alternatives: for example, an average internal combustion engine car is estimated to cost around $20,000 in 2050, whereas a comparable electric vehicle is estimated to cost around $35,000. But on the other hand, 2°C pathways can be cheaper because of the energy efficiency measures that reduce overall energy demand. For example, in the business as usual pathway, global energy demand reaches 610 EJ in 2050, but in the 2°C pathways it is only 380 to 470 EJ. So in the 2°C pathways, we see significant savings on fuels.

Another reason why 2°C pathways can be cheaper is if they involve changes in lifestyle. For example, the "consumer activism" 2°C pathway assumes people travel just as much as under business as usual, but they do so using more public transport, more car sharing, and greater use of car hire (rather than owning their own car); the combined effect of this is reduce the number of cars on the road from 2.3 billion in 2050 in business as usual to 1.4 billion[13]. This reduces spending on cars and roads, and the

12 Of the four plausible 2°C pathways, the cheapest one is "consumer activism": the average annual energy system cost of this pathway over the period 2011 to 2050 could be $2 trillion less than the business as usual pathway (equivalent to a saving of 2% of global GDP). The most expensive of the four plausible 2°C pathways is "low action on forests": the average annual energy system cost of this pathway over the period 2011 to 2050 is $4.2 trillion more than business as usual pathway (equivalent to 3% of global GDP more expensive). This is based on central cost estimates. Business as usual is defined as the "IEA 6DS (approximate)" pathway. Average annual global GDP over the period 2011 to 2050 is $129 trillion.

13 Comparison of number of cars in consumer activism pathway with the number of cars in the IEA 6DS.

savings more than offset the costs of alternative modes of transport and rail infrastructure, leading to a lower total energy system cost overall. Another lifestyle change in this pathway is a shift from beef and lamb consumption towards poultry and pork, which require much less land to produce per kilogram. This change in the type of meat we eat could free up 290 million hectares of land, otherwise used for animal feed and pasture, to ultimately become land for forests, which acts a carbon sink and reduces the need for abatement elsewhere[14].

The Global Calculator also highlights uncertainty in future costs. Forecasting costs 35 years into the future is extremely difficult – for example, in 1980, it is very unlikely that anyone could have forecast that solar panels could fall by around 85% in price by 2010[15]. The Global Calculator shows that in any pathway, the growth in total energy system costs between 2011 and 2050 could be as much as 45% higher or 25% lower than the central case growth assumption[16]. In fact, the uncertainty bands around the business as usual and the 2°C pathways overlap, which means that under some circumstances (e.g. fossil fuel prices higher than expected or renewables prices lower than expected), the abatement pathways would be even cheaper than business as usual. Likewise, if electric vehicles, heat pumps and bioenergy are more expensive than expected and fossil fuels are cheaper, then abatement pathways could be even more expensive.

"The world should now urgently scale up research, development, demonstration and deployment (RDD&D) of clean technologies."

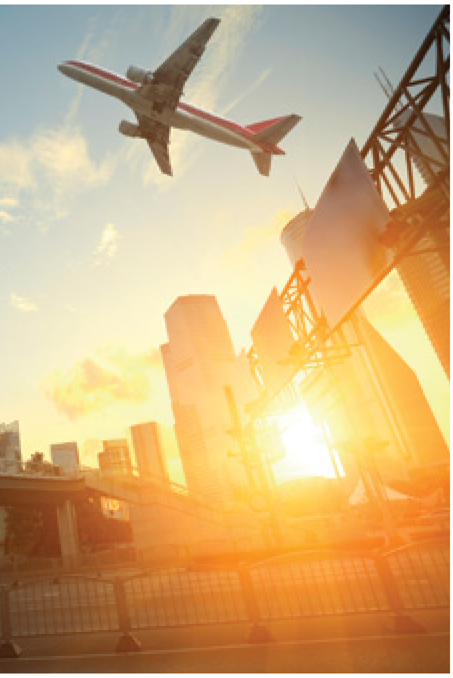
Among the 2°C pathways, capital costs account for over 80% of all energy system costs. So bringing down clean technology capital costs is clearly critical to cutting costs overall. Fossil fuel-based technologies have benefited from over 100 years of research and development to bring down their costs. The world should now urgently scale up research, development, demonstration and deployment (RDD&D) of clean technologies. Of these capital costs, hybrid, electric and hydrogen cars, electricity storage, carbon capture and storage, heat pumps, onshore wind and solar photovoltaics (PV) are the most significant, so a concerted effort to bring down these costs would be particularly helpful[17]. Policy makers have a critical role to play here to invest directly and to create the incentives for businesses to do so.

14 Calculated using the "consumer activism" pathway but comparing it to setting level 2 on "type of meat" lever.

15 DOR NREL Solar Technologies Market Report, Jan 2010. Based on the cost per Watt in 2009 US dollars between 1980 and 2009.

16 For example, for the "consumer activism" pathway, the index of total energy system cost (2011 = 100) is expected to rise to 212 by 2050. The upper estimate of the costs index in 2050 is 305 (44% higher than the point estimate) and the lower estimate of the costs index is 160 (24% less than the point estimate).

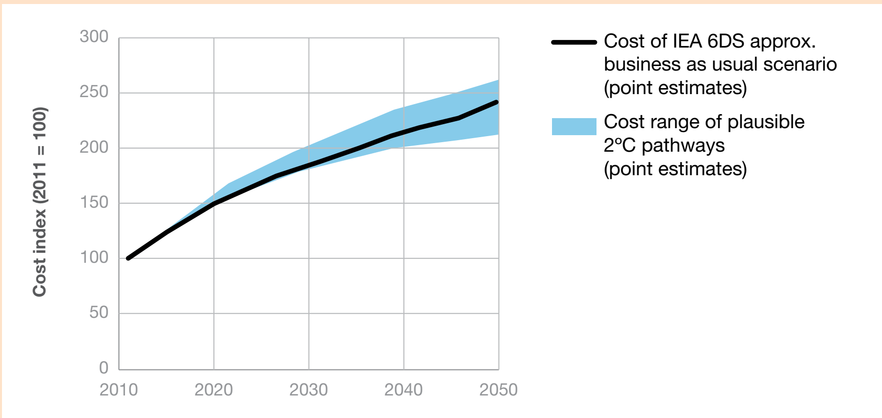
17 Based on the low-carbon technologies with the highest cumulative capital costs in the "distributed effort" pathway.



Contextualising mitigation costs: a thin sliver of a thick wedge

Total world energy system costs are expected to rise by a substantial 140% between now and 2050 under business as usual, as the world continues to develop. The Global Calculator shows that choosing a 2°C pathway instead could add only a thin sliver to this thick wedge. The most expensive plausible pathway shows a cost increase of 160% over the same period (an extra cost equivalent to 3% of global GDP). However, in one plausible scenario (consumer activism), decarbonising the energy system is actually cheaper than business as usual (110% – a saving equivalent to 2% of GDP).

Figure 9: Under business as usual, total energy system cost rises by 140% between 2011 and 2050; the four plausible 2°C pathways rises by a similar extent (110-160%) over the same period



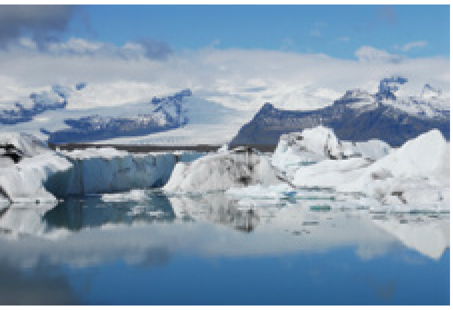
"The Global Calculator showcases some of the evidence from the latest IPCC report and presents it in a user friendly format."

Why aim for 2°C?

This report takes as a starting point the international agreement that 195 countries have made through the UNFCCC process to reduce emissions so that global temperature increases are limited to below 2°C, in order to "prevent dangerous anthropogenic interference with the climate system"[18].

This agreement, made by policymakers, was informed by evidence from IPCC reports and other scientific literature. The science shows that climate impacts increase with temperature and that constraining an increase to 2°C will help avoid the worst effects.

18 UNFCCC, 1992. United Nations Framework Convention on Climate Change, Article 2: Objective. Available at: http://unfccc.int/essential_background/convention/background/items/1353.php



The Global Calculator showcases some of the evidence from the latest c.5,000-page IPCC report and presents it in a user friendly format. It also shows the uncertainty around how the climate could be affected. The tool shows that if the world simply continues with business as usual emissions, this could result in an almost 6°C rise in global mean temperature by the end of this century. This average masks significant regional variations: some regions could face much bigger temperature rises, with over 10°C increase by 2100[19] in the Arctic. The associated socio-economic impacts would be significant. Extreme weather events are likely to become more frequent and severe: for example, the 2003 European heat wave may become the norm towards the middle of the century[20]. An increase in global mean temperature of 6°C is beyond the experiences of mankind: the global temperature difference between now and the last Ice Age around 20,000 years ago (when large areas of currently inhabited land were covered by hundreds of metres of ice) was just 4 to 7°C.

The four example pathways used to generate the key messages in this report are consistent with a 50% chance of constraining temperature increase to 2°C as agreed in the UNFCCC. But even under these pathways we would see impacts. For example, the tool shows that even with the IPCC RCP 2.4 pathway in which temperatures are kept below 2°C, we are still likely to see a 43% reduction in Arctic sea ice by 2100. Some people argue that the world should aim for a more ambitious target (including the Alliance of Small Island States which advocates a commitment to 1.5°C).

"We cannot rely on running out of fossil fuel as a means of abating climate change."

Myth busting

The following have been suggested as potential major solutions for tackling climate change. Their importance is sometimes overstated:

Switch to cleaner fossil fuels

We cannot rely on switching from coal to gas as a major contributor to tackling climate change. All unabated fossil fuels contribute to climate change: for example, an efficient gas plant currently emits 350 gCO_2e/kWh[21]. But to be consistent with a 50% chance of limiting temperature increases to 2°C, we need to decarbonise global electricity generation to near zero gCO_2e/kWh by 2050.

19 IPCC AR5 WG1 Chapter 12, Figure 12.11

20 Study by Stott et al. The 2003 event will be expected on average every other year by the 2040s. Under a BAU scenario it may be a cool summer by the 2080s.

21 Combined Cycle Gas Turbines (CCGT) operating at full capacity currently emit 350 gCO_2e/kWh. See IEA (2014) Energy Technology Perspectives, page 170.

Use up the fossil fuel

Unfortunately, we cannot rely on running out of fossil fuel as a means of abating climate change. The world has enough fossil fuel resources to put the world at risk of a global mean temperature of over 6°C by 2100.

Suck carbon out the atmosphere

We also cannot rely on futuristic technologies to suck carbon out of the atmosphere to solve the climate problem. For example, direct air capture, which involves using chemical processes to directly capture carbon dioxide from ambient air and then storing it underground. These technologies are extremely uncertain in terms of technical feasibility, environmental impact, public acceptability, energy consumption and cost. The very limited evidence on these technologies indicates that they could deliver, at best, around 10 $GtCCO_2e$[22] net emission savings in 2050, which is roughly equivalent to 10% of emissions in 2050 under business as usual[23].

Curb population growth

The global population is expected to increase from 7 billion today to 10 billion in 2050. Curbing population to the UN's lower projected estimate (8 billion) would only save around 10 $GtCO_2e$ by 2050[24]. This is significant but it should not be considered a "silver bullet".

"Explore the Global Calculator model – it's freely available, open source, and comes with 'how to' videos."

Find out more

Businesses interested in the implications for their sector and governments interested in benchmarking their country's progress towards 2°C can read about our findings in more detail on our web site: **www.globalcalculator.org**

You can also explore the Global Calculator model for yourself – it's freely available, open source, and comes with helpful "how to" videos. The tool also contains 2°C pathways from a number of other organisations. You can even have a go at building your own pathway. You can access the model from our web site: **www.globalcalculator.org**. Because a model is only as good as its assumptions, we have also published the entire model as an Excel file so you can examine them. We welcome feedback – email the team at contact@globalcalculator.org

22 Calculated based on the distributed effort pathway with and without GGR level 4.

23 Calculated using the "IEA 6DS (approx.)" pathway.

24 Calculated by comparing emissions from the distributed effort pathway in 2050 (18 $GtCO_2e$) with those from setting the "population" lever to level 3 (8 $GtCO_2e$).

How are these messages generated?

The Global Calculator tool shows that there are many different possible pathways towards 2°C by 2050. To generate the key messages in this paper, we created four plausible pathways which are all consistent with a 50% chance of constraining global mean temperature increase to 2°C[25]. These pathways all have lifestyle settings consistent with economic development. They also assume central projections for global demographic changes.

However, the pathways differ according to the technologies, fuels and land use choices used to service these lifestyles. They have been designed to span a plausible high/low range of effort across each technology, fuel and land use sector. For more detail on these pathways, see the annex and our web site: **www.globalcalculator.org**

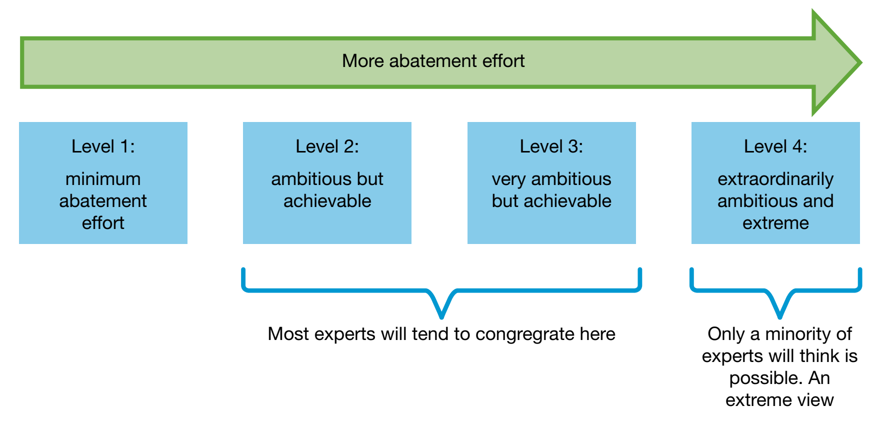
25 Specifically, each of these pathways has at most 3,010 $GtCO_2e$ cumulative emissions by 2100. The IPCC advise that this level of cumulative emissions is associated with a 50% chance of constraining global mean temperature increase to 2°C.

Annex: four plausible 2°C pathways

"The Global Calculator tool has around 40 levers for global greenhouse gas emissions."

Levels 1 to 4 in the Global Calculator

The Global Calculator tool has around 40 levers for global greenhouse gas emissions, covering all choices affecting lifestyle, technology and fuel, land and food and demographics. Users can choose levels 1 to 4 for each lever, as defined below:



This annex describes the four plausible 2°C pathways used to generate the messages in this paper.

Common features of all four pathways:

- Lifestyle levers are set at the same level as the IEA 6DS business as usual scenario (with the exception of the "consumer activism" pathway, in which the levers "mode", "occupancy & load", "car own or hire", "quantity of meat", "type of meat" and "product lifespan & demand" are altered). All four pathways can be considered consistent with projected patterns of economic development.
- Population and urbanisation are set at the central UN projections (level 2).
- Emissions after 2050 are set at around level 2.8 to allow continued reductions toward zero.
- No level 1 or 4s selected in order to avoid extremely ambitious or pessimistic scenarios.
- No use of speculative greenhouse gas removal (GGR) technologies as these are unproven.

1. Distributed effort

http://tool.globalcalculator.org/distributedeffort

In this pathway, the effort to decarbonise is spread fairly evenly across all sectors. Specifically, level 2.8 across all technology and fuel, and land and food levers.

"This pathway shows that protecting and expanding our forest area plays a critical role towards meeting our 2°C target."

2. Consumer reluctance

http://tool.globalcalculator.org/consumerreluctance

In this pathway, consumers are reluctant to accept new technologies that have an immediate impact on them. In particular:

- Transport: continued use of internal combustion engines with very low take up of electric and hydrogen vehicles.
- Buildings: continued use of gas for cooking and relatively low take up of insulation and low carbon heating technologies in homes because the consumer does not want the upheaval.
- Electricity: less use of wind than some of the other 2°C pathways because consumers do not want to see changes to their landscape.
- Wastes and residues: relatively low collection of waste by households.

Instead, the low-carbon activity happens in a way the consumer is less directly aware of:

- Higher use of nuclear and CCS.
- Higher effort on land use (higher food yields, etc.) and relatively high afforestation.

This is a low electrification pathway, with high use of bioenergy.

This pathway shows that it is possible to have low consumer acceptance of technologies that have a direct impact on them. But it means you have to be very ambitious elsewhere, especially across all areas of land use, food production, energy efficiency, transport and industry.

3. Low action on forests

http://tool.globalcalculator.org/lowactiononforests

In this pathway there are insufficient measures in place to expand forests, so non-commercial forest increases by just 1% between 2011 and 2050. Lack of protection of forests means that there is little incentive to boost food

yields, so crop and livestock yields are relatively low. There is very little land for bioenergy, so high electrification is necessary.

This pathway shows that protecting and expanding our forest area plays a critical role towards meeting our 2°C target. Failure to expand forest area significantly means that very ambitious action will have to be taken across a range of other sectors.

4. Consumer activism

http://tool.globalcalculator.org/consumeractivism

In this pathway, people around the world are concerned about technologies perceived at risk of having unintended adverse side effects on the natural environment (e.g. nuclear power or genetically modified crops). Consumers actively embrace changes to the technologies they use and aspects of their lifestyle to ensure we can reach 2°C. Specifically:

"This pathway shows that making changes in our lifestyle can significantly reduce emissions."

- Relatively low nuclear.
- Relatively low crop yields (reflecting reluctance to use genetically modified crops and fertilisers).
- Relatively low livestock intensification (reflecting high value placed on organic/free-range farming practices).
- Some shift from private to public transport.
- Some changes in quantity and type of meat consumed (away from beef and lamb, towards poultry and pork).
- Shift away from a "disposable society" by selecting high effort on the "product lifespan & demand" lever.

This pathway shows that making changes in our lifestyle (for example our dietary and travel choices) can significantly reduce emissions and the effort needed across other sectors.

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