ENERGY DARWINISM II

Why a Low Carbon Future Doesn't Have to Cost the Earth

Citi GPS: Global Perspectives & Solutions

August 2015

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Why a Low Carbon Future Doesn't Have to Cost the Earth

As Thomas Edison presciently pointed out to Henry Ford and Harvey Firestone in 1931, *"We are like tenant farmers chopping down the fence around our house for fuel when we should be using nature's inexhaustible sources of energy - sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."*

While fossil reserves aren't running out, our ability to burn them without limit may be, due to the fact that atmospheric concentrations of CO_2 and equivalents are rapidly approaching the so-called 'carbon budget' – the level that if we go beyond is likely to lead to global warming in excess of the important 2^{o}C level.

It is this that makes the United Nations COP21 meeting in Paris in December 2015 so important; it represents the first real opportunity to reach a legally binding agreement to tackle emissions, given that all parties, including the big emitters, are coming to the table with positive intentions, against a backdrop of an improving global economy.

We live though in an energy hungry world. Global GDP is set to treble by 2060, with two thirds of that growth coming from emerging markets which display significantly greater energy and carbon intensity per unit of GDP than developed markets. Feeding that energy demand and facilitating growth while minimizing emissions will take brave and coordinated decisions on the part of policymakers.

In this report, we examine the likely costs of inaction in terms of the potential liabilities from climate change to see whether we can afford not to act. We also examine whether the world *can* afford to act, by comparing the incremental costs of following a low carbon path to global GDP. Overall, we find that the incremental costs of action are limited (and indeed ultimately lead to savings), offer reasonable returns on investment, and should not have too detrimental an effect on global growth. Nevertheless, our energy choices will have a profound impact on countries, industries and companies, and we examine the implications of a low carbon future in terms of the stranded assets that are likely to result. Finally, we examine the solutions that financial markets and institutions can offer to facilitate this transition to a lower carbon world.

We are not climate scientists, nor are we trying to take sides in the global warming debate, rather we are trying to take an objective look at the economics of the discussion, to assess the incremental costs and impacts of mitigating the effects of emissions, to see if there is a 'solution' which offers global opportunities without penalizing global growth, whether we can afford it (or indeed we can afford not to), and how we could make it happen.

We believe that that solution does exist. The incremental costs of following a low carbon path are in context limited and seem affordable, the 'return' on that investment is acceptable and moreover the likely avoided liabilities are enormous. Given that all things being equal cleaner air has to be preferable to pollution, a very strong "Why would you not?" argument begins to develop.

With the global economy improving post-crisis, interest rates low, the large emitters coming to the table, investment capital keen, and public opinion broadly supportive, Paris offers a generational opportunity; one that we believe should be firmly grasped with both hands.

Action versus Inaction

Limited differential in total bill but potentially enormous liabilities avoided

CUMULATIVE CO_2 EMISSIONS ARE GETTING CLOSE TO THE 3,010 GT 'CARBON BUDGET'

1870	2.4
1910	159.5
1950	434.7
1970	740.0
2010	1844.5
2013	1960

1,050 $GTCO^2$ left to burn to have a 50% chance to reach 2°C

Source: Citi Research, Boden et al. (2013), Houghton et al. (2012)

GLOBAL GDP IS EXPECTED TO TREBLE WITH STRONG GROWTH FROM EMERGING MARKETS

2015
$80 trillion

2060
$260 trillion

2/3rds of global GDP growth is expected from non-OECD countries who tend to be more energy intensive

Source: OECD

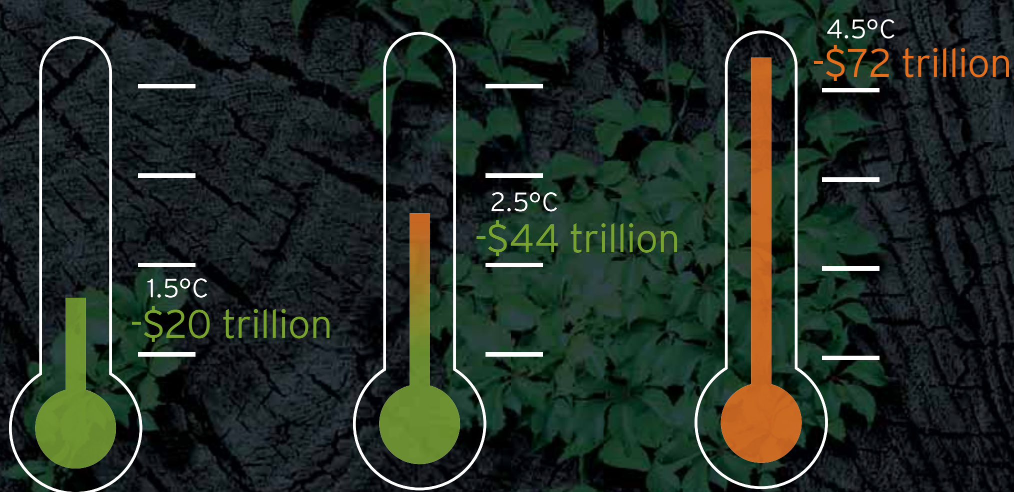
THE ESTIMATED SPEND ON FUEL COSTS AND CAPITAL EXPENDITURES GLOBALLY IS $1.8 TRILLION LESS IN CITI'S ACTION SCENARIO

Power
Transport
Energy efficiency
Other

Source: Citi Research

BUT THE DAMAGE TO GDP FROM THE NEGATIVE EFFECTS OF CLIMATE CHANGE IS SUBSTANTIAL

0% discount rate



Change in global GDP -0.7% -1.1% -2.5%

Source: OECD

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Introduction

Citi forecasts that the sums of money to be spent on energy (both capital expenditure and fuel) over the next quarter century will be unimaginably large, at around $200 trillion. The energy industry is faced with choices, and in this report, we outline two scenarios: 1) a business as usual or 'Inaction' on climate change scenario, and 2) a different energy mix that offers a lower carbon alternative. We find that out to 2040 the levels of spend are remarkably similar; indeed the 'Action' scenario actually results in an undiscounted saving of $1.8 trillion over the period, as while we spend more on renewables and energy efficiency in the early years, the savings in fuel costs in later years offset earlier investment.

If the scientists are correct, the potential liabilities of not acting are equally vast. The cumulative 'lost' GDP from the impacts of climate change could be significant, with a central case of 0.7%-2.5% of GDP to 2060, equating to $44 trillion on an undiscounted basis. If we derive a risk-adjusted return on the extra capital investment in following a low carbon path, and compare it to the avoided costs of climate change, we see returns at the low point of between 1% and 4%, rising to between 3% and 10% in later years.

So can we afford to act? Examining the extra spend required in our 'Action' scenario in the context of global GDP, we find that on an annual basis we only have to spend around 0.1% of GDP more on energy, and that on a cumulative basis at its worst point, the extra investment only amounts to around 1% of global GDP. Moreover, against a backdrop of secular stagnation, that extra investment may actually help to boost growth.

These changes in energy mix inevitably have significant implications in terms of which fossil fuel assets will be burnt, and which not. Some studies suggest that globally a third of oil reserves, half of gas reserves and >80% of coal reserves would have to remain unused before 2050 for us to have a chance of staying below the 2^{o}C limit. We examine the issue of unburnable carbon and stranded assets, in particular in which countries, industries and companies they are located, and find that at current prices, around $100 trillion of assets could be 'carbon stranded', if not already economically so. The clear loser stands to be the coal industry, though we examine the economics and potential offered by carbon capture and storage.

So how do we make this investment happen? Almost all of the growth in energy demand is forecast to come from emerging markets, while most of the new investment in developed markets will be into energy efficiency, both of which represent challenges to investment. While Development Finance Institutions have to date provided much of the investment in emerging markets, these now find themselves effectively 'maxed out'.

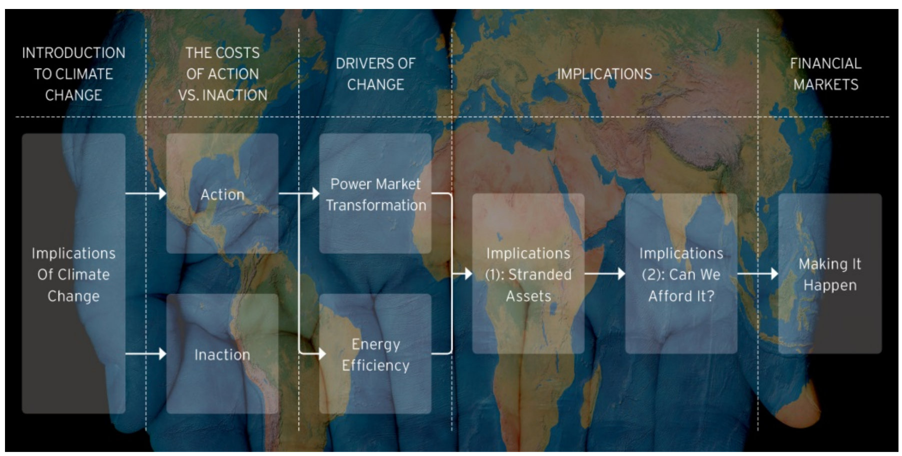
There is a clear need for the investment, balanced by enormous investor appetite for these types of investments; the missing link has been the lack of, and quality of the investment vehicles available. Hence financial markets must innovate to facilitate investment via the creation of new instruments, vehicles and markets. We see the greatest opportunity in the credit markets, yet the challenge will be to raise the quality of the instruments available to investment grade via credit quality enhancement, securitization and other methods. We examine the potential solutions that financial markets can offer, and highlight the enormous opportunity that this presents.

Overview

This report examines the threats and opportunities presented by climate change, looks at its implications and how to mobilize the finance to tackle it.

- **Introduction to Climate Change**: The report begins with an overview of climate change, emissions levels and what the forthcoming United Nations meeting in Paris in December 2015 is attempting to achieve (and why).
- **The costs of inaction and action:** We examine the costs of inaction in terms of GDP potentially lost due to climate change, and compare this with the potential costs of action in terms of mitigating climate change.
- **Drivers of change**: The next chapters examine the drivers of this mitigation strategy, namely the transformation of the power market, and lower energy use via increased investment in energy efficiency.
- **Implications of change:** We then examine the implications of that investment to help prevent climate change, in terms of its effect on global GDP, but also the effect of the energy mix shift in creating stranded assets in certain industries.
- **Making it happen:** Finally, we examine the methods and instruments through which financial markets, financial institutions, regulators and policy makers can enable the capital to flow to address this important issue.

Figure 1. Structure of the Report



Source: Citi Research

An Introduction to Climate Change

Highlights

- The UN COP21 meeting will be held in Paris in December 2015 with the aim of reaching a global legally binding agreement designed to keep global temperature increases to below 2°C, a level designed to avoid the worst effects of climate change

- Prior to the meeting, countries must submit their pledges and plans to reduce emissions which can then be aggregated and compared to the so-called 'carbon budget' – the amount of greenhouse gases (GHG) we can still emit before temperatures are committed to rising above 2°C. This then forms a starting point for negotiations in how the world can go further, given that these aggregated pledges are likely to be above the 'carbon budget'.

- So far a total of 21 countries and the EU have submitted their pledges to reduce GHG emissions. These countries represent over 56% of total GHG emissions that are currently emitted.

- Another objective of the COP21 meeting is the mobilization of $100 billion per year from developed countries to developing countries. It is not yet quite clear how such funds will be mobilized, however an initial capital of $10.2 billion has been pledged by 33 countries through the Green Climate Fund.

- There are three key ways to tackle climate change, namely adaptation, mitigation and geoengineering. We focus mainly on mitigation in this report as it represents shorter term action and is more easily quantifiable.

- The energy sector contributes two thirds of greenhouse gas emissions with CO_2 emissions representing 90% of the total energy-related emissions. The rest of the greenhouse gas emissions are attributed to agriculture, land use and forestry sector and other industrial processes.

- Coal represented 43% of annual CO_2 emissions in 2013, followed by oil (38%) and gas (18%). The electricity sector was responsible for emitting 42% of energy-related CO_2 emissions.

- In 2013, China was responsible for emitting over 27% of total energy-related CO_2 emissions, followed by the US (14%) and the EU (9%). Cumulative CO_2 emissions show a different picture with the US being the largest emitter followed closely by the EU.

- To limit temperature increase to 2°C would require CO_2 emissions (not including CH_4 and N_2O) to be limited to approximately 3,010GT CO_2. We have already emitted more than 60% of this total 'carbon budget', leaving little room to expand CO_2 emissions if we are serious about limiting the temperature increase to 2°C.

- If it wasn't for land and ocean 'carbon sinks', annual carbon dioxide concentrations would be accumulating in the atmosphere at a much higher rate.

Introduction

Over the years, scientists have become increasingly confident that humans are re-shaping the Earth's climate. Scientifically, much of what was needed to start worrying about global warming or climate change was known in the late 1950's, although society generally didn't become concerned about the topic until the 1980's. From the late 1980's, the regulation of climate change started gathering steam and scientists through the use of super computer models were able to start studying the climate in more detail. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created and charged with assessing the science of climate change, bringing together climate change scientists, social scientists, engineers and other experts to discuss the new science on this critical topic.

One purpose of the IPCC was to determine whether formal diplomatic talks would need to be undertaken to discuss the issue of greenhouse gas emissions. The conclusion was obviously a 'yes' and a new treaty called the United Nations Framework Convention on Climate Change (UNFCCC) was signed in Rio in 1992, by 108 heads of state (Victor D.G., 2011)[1]. The objective of the treaty was to 'stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (UNFCCC). Since then, the parties of the convention have met annually from 1995 in the Conferences of the Parties (COP) to assess the progress in dealing with climate change. The Kyoto Protocol was signed in 1997 at one such meeting, which after ironing out all the details finally came in force in 2005.

Parties in Cancun agreed to limit temperature increase to 2°C

The Cancun agreement in 2010 stemmed from another COP meeting, and stated that in order to limit the damage from climate change, global temperature rise should be limited to 2°C from pre-Industrial average levels. The COP process has been successful in bringing together countries and in mobilizing scientists, non-governmental organizations (NGO's) and others to discuss climate change. However the process has been slow and has also been criticized for not being able to form a legally binding agreement accepted by all to reduce greenhouse gas emissions over time.

The 2°C Temperature Goal

The 2°C temperature limit first surfaced during a 1977 paper on Economic Growth and Climate Change written by William Nordhaus and has since become an international standard. The Cancun agreement formally recognized that parties should take action to limit temperature increase to below 2°C thereby hopefully avoiding some of the worst implications of climate change. They recognized that to achieve this goal, greenhouse gas emissions would need to be cut, which in turn has encouraged economists, scientists and engineers to identify policy scenarios that can meet this temperature increase. Thomas Stocker (the co-chair of the IPCC) has stated that, "The power of the 2°C is that it is pragmatic, simple and straightforward to understand and communicate all important elements when science is brought to policymakers".

[1] David G. Victor, 2011, Global Warming Gridlock, Cambridge University Press, UK

Why Now? The UN COP21 Meeting in Paris

From 30th November to the 11th December 2015, heads of representatives of states will once again gather, this time in Paris for the COP21 meeting. The aim of this meeting is:

1. To set up a new binding international agreement, applicable to all countries, with the aim of keeping global warming to 2°C, and

2. To mobilize funds to allow developing countries to both adapt to and mitigate climate change impacts.

COP21 provides the best opportunity to date to reach a binding international agreement on climate change

The aim is to have such an agreement in force by 2020. The difficulty of reaching a global climate agreement is due to the fact that climate change is considered a global negative externality which requires costs to be borne today, whilst the benefits would be reaped (though not explicitly felt, given that is an avoidance of an outcome) in the future.

There have been several COP meetings held before which have failed to reach an international legal binding agreement on the reduction of greenhouse gas emissions. The Kyoto Protocol that was signed in 1997 and came into force in 2005, was the closest to reaching such an objective, but still fell short of the mark. The protocol required 'Annex 1' countries (OECD countries plus countries with economies in transition) to reduce emissions by an average of 5% from 1990 levels over the five year period from 2008 to 2012 (Nordhaus, 2013)[2]. Developing countries were exempt from such targets and were only responsible for reporting their emissions over time. The protocol was an ambitious attempt to harmonize the policies in different countries, however countries did not find it economically attractive. During negotiations the US had agreed to reduce its GHG emissions, however back home the government stated that this was unachievable and abandoned the treaty completely.

The Kyoto agreement came closest, but was still flawed

There was also another problem with the treaty in that at the time of signing, the countries that agreed to the treaty emitted two thirds of the total greenhouse gas emissions; however this barely covered one-fifth of what was emitted in 2012. During the interim period, emissions grew far more rapidly in non-covered countries particularly in developing countries such as China (Victor D.G, 2011)[3]. The meeting in Copenhagen in December 2009 aimed to establish a replacement of the Kyoto Protocol, given that the limits agreed in Kyoto expired at the end of 2012. The meeting failed to achieve a binding agreement on GHG reductions amongst country participants, though they did create the Cancun agreement which recognized the scientific view of limiting temperature increase to 2°C as stated in the introduction above.

[2] Nordhaus, 2013, The Climate Casino: Risk Uncertainty and Economics for a Warming World, Yale University Press
[3] Victor, D.G. (2011)

The Clean Development Mechanisms (CDM) – Article 12 of Kyoto Protocol

Three market based mechanisms (international emissions trading and two offset programmes – Joint Implementation (JI) and Clean Development Mechanism (CDM)) were created to help developed countries meet their emission targets under the Kyoto Protocol more cost-effectively.[4] While there have been only a few projects under JI, a lot of work has gone into the CDM. CDM allows companies and Annex I countries (i.e. OECD members plus countries with economies in transition) to buy Certified Emission Reduction credits (CERs) from CDM projects in developing countries instead of reducing their own emissions. This work, driven primarily by the demand for low cost emissions reduction credits under from the EU Emissions Trading System (EU-ETS) and other countries that have ratified the Kyoto Protocol, created a global market for GHG emissions offsets. The mechanism allows investment to be targeted at the most cost-efficient emissions reductions first, wherever in the world they may be located.

According to the CDM Policy dialogue, over the past decade CDM has mobilized more than $215 billion in investments in developing countries and helped reduce 1 billion tonnes of GHG emissions.[5] However, it has also been criticized for allowing countries/companies to obtain millions of dollars in CERs for projects that they would have done anyway without the CDM in place. There has also been a problem between the balancing of supply and demand of CERs, which has decreased the price of credits over time. The uncertainty around a global agreement (the commitments under the Kyoto Protocol have expired) and the lack of demand for such credits have crippled the Clean Development Mechanism over time, although an agreement at the COP21 meeting in Paris could revive the CDM.

COP21 in Paris will be the first time countries including the big emitters have come together with positive momentum towards reducing GHG emissions

The (future) damage caused by climate change and the cost of preventing it increase over time (with even some potential points of no return), and hence time is a factor to be considered. The reason COP21 is so important is that it will be the first time that all parties (in particular some of the big emitters) have come to the table with generally positively aligned intentions, against a backdrop of an improving global economy.

21 countries and the EU have submitted pledges (INDCs) to the UNFCCC to reduce GHG emissions below a baseline level

Before the COP21 meeting, each country must publish their intended contribution to the global climate effort, a so–called 'INDC' (Intended National Determined Contribution); a new development in international climate negotiations. Shortly before the meeting, the UNFCCC secretariat will publish a summary of these contributions, to give a possible indication of the cumulative effect of all these national efforts. Twenty-one countries and the European Union (collectively covering over 56% of global greenhouse gas emissions) have submitted their INDC's at the time of writing this report, as shown in Figure 2. The EU's pledge to cut GHG emissions by 40% in 2030 compared to its 1990 level would see the region becoming one of the world's least carbon intensive economies, whilst the United States pledge would also deliver a major reduction in GHG emissions of 26 - 28% by 2025 relative to its 2005 levels. China, the largest absolute emitter of GHG emissions has echoed the statement that it made in 2014 by pledging to achieve a peak in CO_2 emissions by around 2030, an important change in direction given how its emissions have increased over recent years. It has also stated that it would cut its CO_2 emissions per unit of GDP by 60-65% from 2005 levels by 2030 and will increase its non-fossil fuel sources to about 20% by the same date.

[4] Gillenwater M, Seres S, (2011), The Clean Development Mechanism, A review of the first international offset program, Prepared for the Pew Centre on Global Climate Change.
[5] CDM Policy Dialogue (2012) Climate Change, Carbon Markets and the CDM, A call to action

Approaches are likely to be country-specific, rather than a single global carbon market

We believe that a single global carbon market is not likely to be the outcome from COP21, rather that countries will select their own approaches to meeting their INDCs. These might involve market mechanisms such as carbon pricing or energy efficiency incentives, removal of fossil fuel subsidies, various types of regulatory constraints, or some combination of these approaches. Supranational mechanisms such as the CDM (Clean Development Mechanism) or JI (Joint Implementation) might allow trading or interchangeability between these schemes.

For example, in its own INDC submission, the US points to measures to reduce emissions including regulations to cut pollution from new and existing power plants, vehicle fuel economy standards, standards to address methane emissions from landfills and the oil & gas sector, constraints on hydro fluorocarbons and codes relating to buildings, appliances and equipment.

Mobilization of Funds

$100bn per annum must be mobilized from developed to developing countries

A commitment was agreed at the Copenhagen COP meeting that developed nations (from private and public, bilateral and multilateral sources) would jointly provide $100 billion per year (from 2020) to help developing nations address climate change. A key objective of the COP21 meeting will be the mobilization of these funds, via financing, technology and capacity building. Some of this money will pass through the Green Climate Fund, which has received an initial capital of $10.2 billion from 33 governments last year (as of April 2015, 42.5% were contributions that were actually signed, the rest are pledged contributions). The purpose of the fund is to promote the shift towards low-emission and climate-resilient development pathways by providing support to developing countries to limit their greenhouse gas emissions and to adapt to climate change. The majority of the funds in the Green Climate Fund should be counted as part of the $100 billion that has been pledged, however only a certain non-predetermined part of the $100 billion will pass through the Green Climate Fund.

Figure 2. INDC Submitted by Countries/Regions

Country/ Region	INDC Pledge	Emissions (Base Year) MT CO_2e	% World GHG Emission	Mechanisms Proposed
Andorra	37% reduction in GHG emissions by 2030 from a BAU scenario.	Not applicable	Not available	
Liechtenstein	40% reduction in GHG emissions by 2030 from 1990 levels.	Not applicable	Not available	Possibility to achieve emissions reductions abroad.
Gabon	50% reduction by 2025 compared to BAU scenario.	Not applicable	0.02%	
Russia	Limiting GHG emissions to 70-75% of 1990 levels by the year 2030.	Base year 1990	4.8%	This is subject to absorbing capacity of forests.
US	26-28% reduction by 2025 compared to 2005 levels.	6135 (2005)	12.2%	Domestic legislation.
Mexico	Unconditionally reduce 25% of GHG and short lived climate pollutants emissions below 2013 levels. This could further increase to 40% subject to a global agreement.	663 in 2012- (2013 figures are not available)	1.6%	National Climate change policy.
Norway	40% reduction by 2030 compared to 1990 levels.	52 (1990)	0.06%	Collective delivery within the EU.
EU	Binding target of at least a 40% reduction by 2030 compared to 1990 levels.	5640 (1990)	8.6%	Binding legislation.
Switzerland	To reduce GHG emissions by 50% by 2030 compared to 1990 levels, corresponding to an average reduction of emissions by 35% over the period 2021-2030.	53.3 (1990)	0.1%	Switzerland will achieve its targets mainly domestically and will partly use carbon credits from international mechanisms.
Canada	To reduce GHG emissions by 30% below 2005 levels by 2030.	~730 (2005)	1.8%	Legislative instruments which includes transportation, electricity and renewable fuels regulations which encourage phasing out of coal-fired generation and stringent GHG emission standards for heavy duty vehicles.
Morocco	Two targets are proposed: an unconditional target of 13% GHG reduction and a conditional target of an additional 19% GHG reductions compared to a BAU emissions scenario in 2030.	~90(2010)	0.15%	The implementation is contingent upon gaining access to new sources of finance and enhanced support. Meeting the conditional target would require $45 billion in investment of which $35 billion is conditional upon international support such as the Green Climate Fund.
Ethiopia	To limit its net GHG emissions in 2030 to 145 MT CO_2e or lower. This means that Ethiopia is planning to reduce its GHG emissions by 64% from the BAU scenario in 2030.	Not applicable	0.30%	The full implementation of Ethiopia INDC is contingent upon a multi-lateral agreement being reached among Parties that enables Ethiopia to get international support.
Serbia	To reduce GHG emissions by 9.8% below 1990 emissions level by 2030.	Not applicable	-0.04% (0.1% w/out LUCF)	The introduction of a climate change strategy with an action plan that should be finalized in 2017 which will further define the activities, methods and implementation deadlines.
Iceland	Iceland aims to be part of a collective delivery by European countries to reach a target of 40% reduction in GHG emissions by 2030 compared to 1990 levels. A precise commitment has yet to be determined and is dependent on an agreement with the EU.	Not available	0.01%	Continue to participate in EU Emissions Trading Scheme (ETS) and to determine a target for emissions outside the EU-ETS scheme.
China	Aims to (1) achieve a peaking of CO_2 emissions by 2030, making best efforts to peak earlier; (2) to lower CO_2 emissions per unit of GDP by 60-65% from 2005 level; (3) to increase the share of non-fossil fuels in primary energy to 20% and (4) to increase the forest stock volume by 4.5 billion cubic meters on the 2005 level.	Not applicable	22.5%	Implementing of national strategies on climate change including the National Program on Climate Change (2014-2020) and to improve regional climate change policies. They will also implement measures to control total coal consumption, develop nuclear, scale up renewables and control emissions from other industry such as iron, steel etc. and from building and transport sectors.
Republic of Korea	To reduce GHG emissions by 37% from a BAU scenario by 2030.	850.6 (BAU)	1.4%	Partly use carbon credits from international market mechanisms and nationwide Emissions Trading Schemes.
New Zealand	To reduce GHG emissions to 30% below 2005 levels by 2030.	Not available	0.1%	Rests on the assumption that rules agreed by the Parties will allow for unrestricted access to global carbon markets.
Singapore	To reduce GHG emissions by 36% from 2005 levels by 2030.	40.9 (2005)	0.12%	Domestic efforts but will study the potential of international market mechanisms.
Japan	To reduce GHG emissions by 26% by 2030 compared to 2013 levels (25.4% reduction from its 2005 levels).	~1380 (2013)	2.5%	They provide detailed measures on how to reduce emissions in different sectors through efficiency improvements, better technology, energy saving standards, renewable resources, better forest management etc.
Marshall Islands	To reduce GHG emissions to 32% below 2010 levels by 2025.	Not available	<0.00001%	They identify several areas where action would be taken including efficiency improvements, electric vehicles etc. These actions depend on availability of finance and technology support.
Kenya	To abate GHG emissions by 30% by 2030 relative to a BAU scenario.	143 (BAU)	0.15%	Promotion of energy and resource efficiency, improvement of tree cover and deployment of clean energy technologies etc. This is subject to available finance, investment, technology and capacity building.
Monaco	To reduce GHG emissions by 30% and 50% by 2020 and 2030 respectively from 1990 levels.	Not available	N/A	Implementation of domestic measures and possible participation in international mechanisms.

Note: BAU = Business as Usual and LUCF = Land Use Change and Forestry, % of World GHG emissions is including LUCF and based on 2012 levels
Source: UNFCC, Citi Research

What are Greenhouse Gas Emissions?

Anthropogenic GHG emissions include CO_2, CH_4, N_2O and F-Gas; these gases cause a gradual heating of the Earth

Science appears to show that that Earth's climate is rapidly changing, as a result of an increased concentration of greenhouse gases caused by the combustion of fuels, deforestation and other human activities. These gases create a 'greenhouse effect' trapping some of the sun's energy and warming the climate in the process. The Earth has a delicate balance between the radiation it receives from space and the radiation it reflects back into space; the exchange of this radiation is known as the 'greenhouse effect'. It is this equilibrium that makes the Earth habitable, and without this equilibrium the Earth would either be too cold or too hot to live in. According to scientists, anthropogenic greenhouse gas emissions such as carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Fluorinated gases (F-Gas) act like a blanket, absorbing the sun's radiation and preventing it from escaping back into space. The net effect is a gradual heating of the Earth, a process which has been termed 'global warming'.

Carbon dioxide is emitted through the burning of fossil fuels and through a change in land-use such as deforestation. Land can also remove CO_2 from the atmosphere through reforestation, improvements in soil and other activities. Agricultural activities, waste management and the extraction and mining of fossil fuels contribute to CH_4 emissions. F-gases are emitted through industrial processes, refrigeration and the use of a variety of consumer products. Black carbon also contributes to the warming of the atmosphere though it is not a gas, rather an aerosol or a solid particle (EPA). According to the IPCC's Fifth Assessment report, concentrations of CO_2, CH_4 and N_2O have exceeded pre-Industrial average levels by about 40%, 150% and 20%, respectively.

Carbon dioxide (CO_2) makes up 76% of all GHG emissions

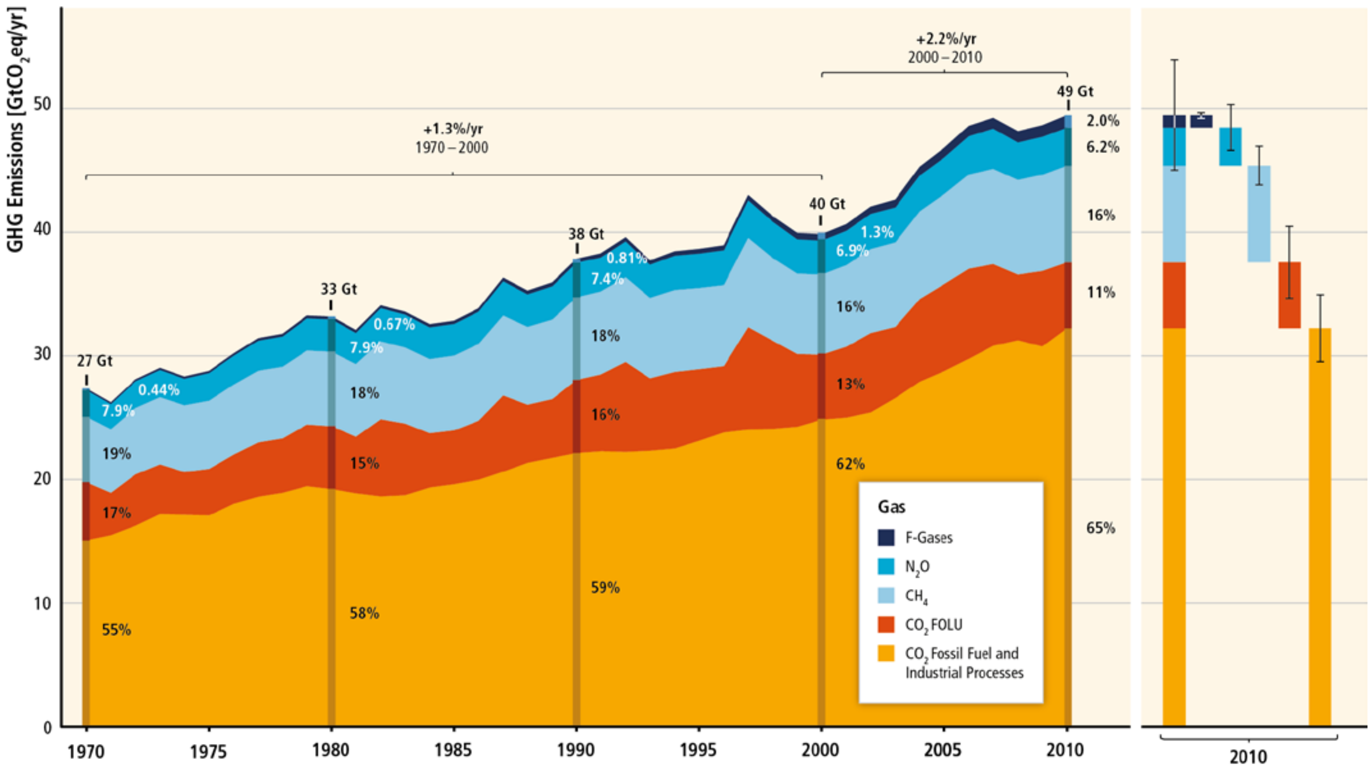
CO_2 makes up the majority of the greenhouse gas (65% from fossil fuels and other industrial processes and 11% from agriculture, forestry and other land use), followed by methane (16%) and nitrous oxide (6.2%). The effect of each gas on climate change depends on three main factors:

1. The concentration or abundance of the gas found in the atmosphere
2. How long it stays in the atmosphere, and
3. How strongly it impacts global temperatures, as some gases are more effective at warming the planet than others.

For each greenhouse gas, a global warming potential has been calculated, reflecting a combination of the second and third factors above by the US Environment Protection Agency[6], to allow a comparison of the contribution of each gas.

[6] US EPA, Overview of Greenhouse Gases
www.epa.gov/climatechange/ghgemissions/gases.html

Figure 3. Total Annual Anthropogenic GHG Emissions By Groups of Gases, 1970-2010



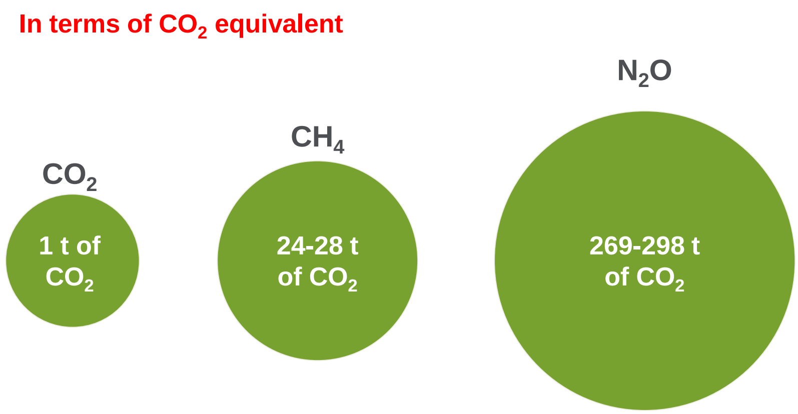
Source: : IPCC (2014)

Global Warming Potential

Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. It is a measure of how much energy the emissions of one tonne of a gas will absorb over a given period of time (usually 100 years), relative to the emissions of one tonne of carbon dioxide. The larger the GWP, the more that gas warms the Earth compared to CO_2 over the given time period.[7] It provides a common unit of measure, which allows scientists to compile national greenhouse gas inventories and compare emissions-reduction opportunities across sectors and gases. Based on GWP calculations, 1 tonne of methane is approximately 28-34 times more effective at warming the atmosphere than carbon dioxide, whilst one tonne of nitrous oxide is 265-298 times more effective at warming the atmosphere than carbon dioxide. However carbon dioxide is the largest anthropogenic greenhouse gas (~76% in 2010) and remains in the atmosphere for a very long time, whilst methane (~16% in 2010) and nitrous oxide (~6% in 2010) emitted today will remain in the atmosphere for a decade and 100 years respectively.

[7] US EPA, Understanding Global Warming Potentials www.epa.gov/climatechange/ghgemissions/gwps.html

Figure 4. Carbon Dioxide Equivalents for Different GHGs



Source: Citi Research

Energy-Related CO_2 Emissions

2/3 of all GHG emissions are emitted by the energy sector

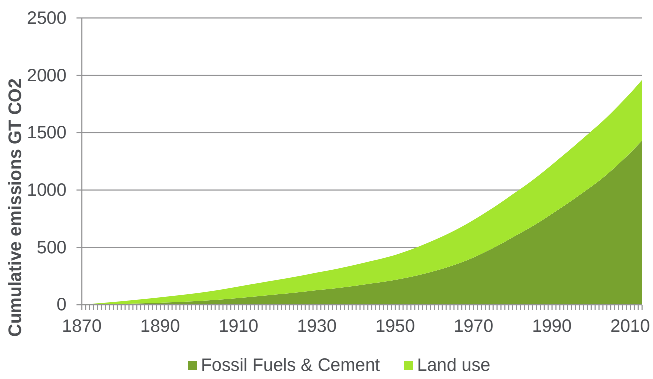
The energy sector contributes two thirds of greenhouse gas emissions, the rest being attributed to land use and forestry and other industrial processes. 90% of the energy-related emissions are CO_2 from fossil fuel combustion, with methane from oil and gas extraction, transformation and distribution accounting for just under 10%. The remainder are nitrous oxide emissions from energy transformation, industry, transport and buildings.

The Energy sector is responsible for 73% of cumulative CO_2 emissions

Since CO_2 emissions accumulate in the atmosphere over time, it is important to look at both cumulative and annual emissions. Figure 5 shows the cumulative CO_2 emissions from 1870 to 2013 from both energy and land use. The energy sector contributed 73% of these emissions, with the rest being attributed to a change in land use and agricultural practices. Figure 6 shows the annual CO_2 emissions from energy and land use from 1959 to 2013 together with the carbon sinks, i.e. natural 'reservoirs' which remove carbon from the atmosphere. Annual CO_2 emissions from fossil fuels (and cement) increased from an estimated 6GT in 1950 to 36GT of CO_2 in 2013. According to the International Energy Agency (IEA), CO_2 emissions stalled in 2014, unchanged from 2013, despite the global economy increasing by approximately 3% in the same year; potentially marking an important delinking (or the start of one) between CO_2 and GDP.

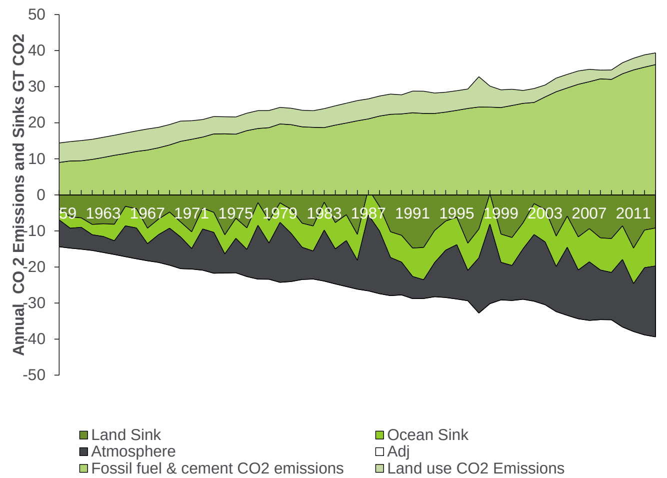
The oceans, land and atmosphere are the three main sinks for carbon dioxide and as we emit more carbon dioxide each year, each of the three sinks absorb more carbon. If it wasn't for land and ocean sinks, annual carbon dioxide concentrations would be accumulating in the atmosphere at a higher rate. Although we tend to focus on growing atmospheric carbon concentrations, ocean acidification (the ongoing decrease in the pH of the Earth's oceans caused by the uptake of carbon dioxide from the atmosphere) also has potentially serious ramifications.

Figure 5. Cumulative CO_2 Emissions from Energy and Land Use



Source: Bodel et al. (2013), Houghton et al. (2012), Citi Research

Figure 6. Annual CO_2 Emissions from Energy and Land Use and Carbon Sinks



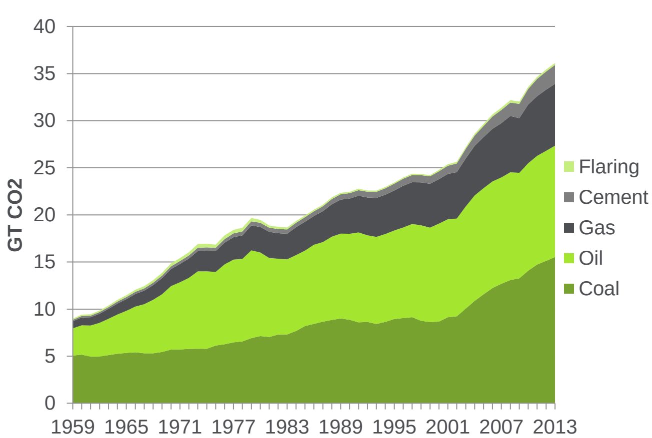
Source: Bodel et al. (2013), Houghton et al. (2012), Tans and Dlugokenckys, Le Quéré et al. (2013), Citi Research

Energy-Related CO_2 Emissions by Fuel and Sector

The electricity and heat sector was the largest emitter of energy-related CO_2 emissions

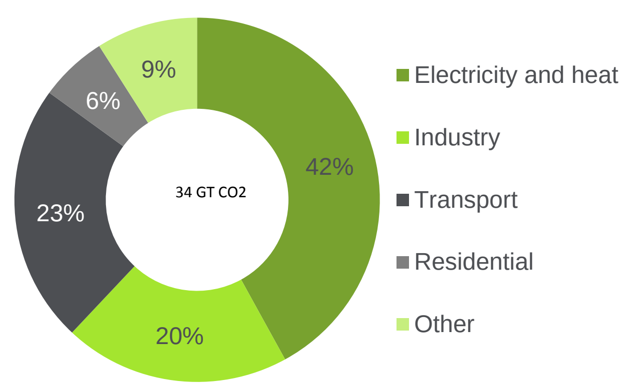
Although coal only represents 30% of total primary energy supply, it accounted for 43% of energy-related CO_2 emissions in 2013 due to its heavy carbon content per unit of energy released. Compared to gas, coal is on average nearly twice as emission intensive. Oil and gas contributed 33% and 18% of emissions respectively in 2013 (Figure 7). Figure 8 shows that the electricity and heat sector was responsible for 42% of energy-related CO_2 emissions, followed by the transport sector (23%) and industrial sector (20%). Over 40% of the generation of electricity and heat worldwide relies on coal; in fact countries such as Australia, China and India produce over two thirds of their electricity and heat through the combustion of coal. However, as renewables are becoming cheaper, they could replace some of the coal consumption in future years.[8]

Figure 7. Annual Energy-Related CO_2 Emissions by Fuel Type (includes cement)



Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Figure 8. % of Annual Energy-Related Emissions by Sector



Source: IEA (2014), Citi Research

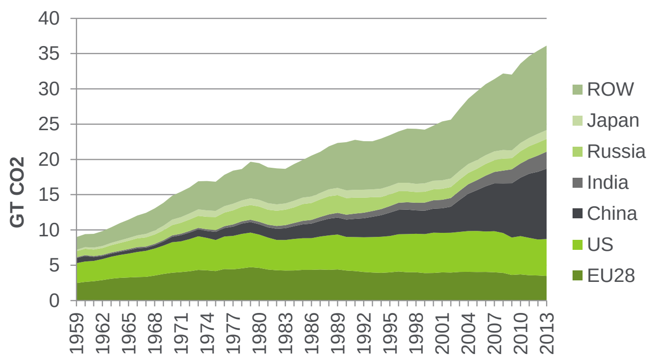
8 BP Energy Outlook. 2035. www.bp.com/energyoulook

Energy-Related CO_2 Emissions by Country

In 2013 China was the largest emitter of CO_2, however on a cumulative basis the US has been the largest CO_2 emitter

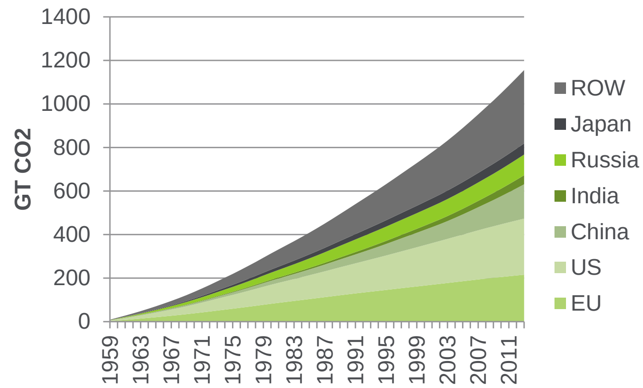
In 2013, China was responsible for emitting over 27% of total energy-related CO_2 emissions, followed by the US (14%) and the EU (9%). Figure 9 below shows the dramatic increase in China's energy-related CO_2 emissions between 2002 and 2013. Cumulative CO_2 emissions from 1959 to 2013 (Figure 10), show a different picture, with the US responsible for emitting 22% of total emissions, followed by the EU (19%) and then China (14%). China in its INDC has pledged to peak its CO_2 emissions by around 2030, and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. An indirect benefit of reducing emissions is a reduction in air pollution (a major issue in China's cities) especially from coal-fired plants, which is driving China to close inefficient coal plants and increase its share of nuclear and renewables.

Figure 9. Annual Energy-Related Emissions by Country (incl. cement)



Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Figure 10. Cumulative Energy-Related Emissions by Country

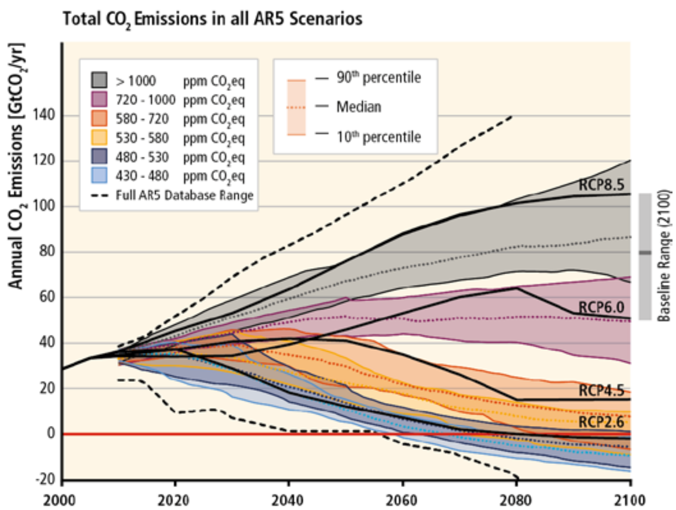


Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Future Emissions and the 'Carbon Budget'

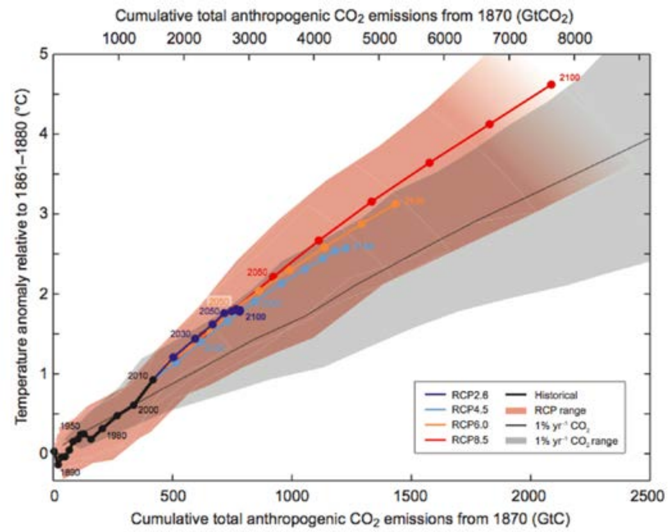
Climate scientists use a vast array of monitoring data to create models that reproduce the mechanisms of the climate system. To calculate how human activities could affect the climate, scientists take into account greenhouse gas concentrations, pollution and changes in land use in their models. These concentrations and changes depend on future social and economic development including things such as economic growth, technological change, population growth, innovation etc. Scenarios are therefore used to explore these issues in more detail. The IPCC in their last report identified four new scenario's called Representative Concentration Pathways (RCP's). These four RCPs include one mitigation scenario (RCP 2.6), two stabilization scenarios (RCP 4.5 and 6), and one scenario with very high greenhouse gas emissions (RCP8.5). Figure 11 and Figure 12 show the annual and cumulative CO_2 emissions respectively under these RCP scenarios.

Figure 11. Annual CO_2 emissions under RCP scenarios



Source: Clarke et al. (2014)

Figure 12. Cumulative CO_2 emissions under RCP scenarios



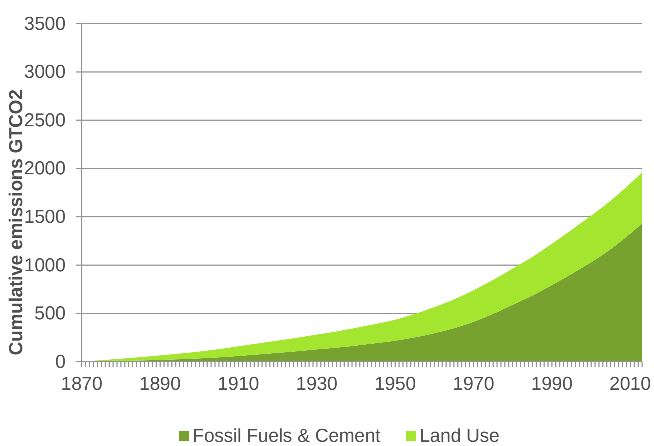
Source: IPCC, 2013

We have already emitted over 60% of the total 'carbon budget', and therefore we have little room to expand if we want to limit warming to 2°C.

The Carbon Budget

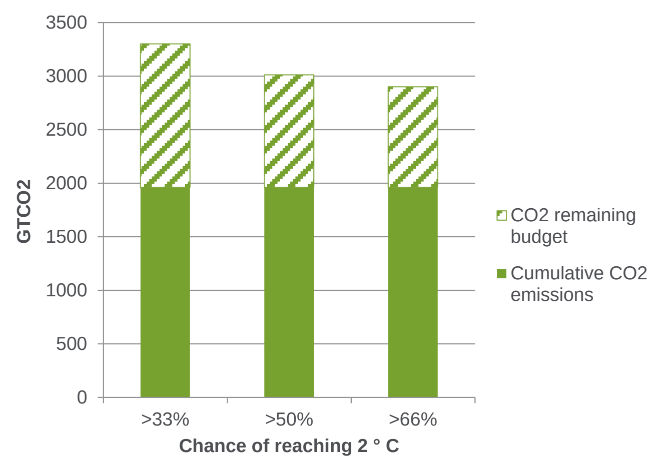
The RCP 2.6 scenario creates a pathway designed to offer a 50% chance of limiting global temperature increases to 2°C. To reach this target, greenhouse gas emission concentrations in the atmosphere would need to stabilize to about 445 to 490 ppm CO_2 equivalent. Ultimately this means that global cumulative CO_2 emissions would need to be limited to approximately 3,010GT CO_2 (IPCC, 2014), the so-called 'carbon budget'. Figure 13 and Figure 14 below show that we have already emitted more than 60% of the total 'carbon budget', leaving little room to expand CO_2 emissions if we are serious in wanting to limit temperature increases to 2°C.

Figure 13. Cumulative CO_2 Emissions from 1870 to 2013 in Comparison with the 'Carbon Budget'



Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Figure 14. Global 'Carbon Budget'



Source: IPCC (2013)

What Happens if We Don't Meet the 'Carbon Budget'?

While the impacts of climate change are very difficult to define with any certainty, key negative impacts include:

- A reduction in crop productivity which would have an impact on global food production.
- A reduction or increase in the availability of water resources (e.g. floods and drought).
- Sea-level rises which could affect coastal cities.
- Potentially the extinction of certain species.

This list is far from exhaustive, and it is perhaps more sobering to consider it in terms of associated human consequences, for example famine, drought, associated health issues, mortality rates and mass population displacement to name but a few.

The aim of the COP21 meeting in Paris is to finalize a legal binding agreement between all countries to reduce greenhouse gas emissions over time, thereby increasing the chance of limiting temperature increases to 2°C. The 'carbon budget' aims to provide an simple metric which world leaders could agree to, and against which aggregated INDC's could be compared.

Action vs. Inaction: Counting the Cost of our Energy Choices

Highlights

- Almost one fifth of the world's population still lack of access to power, with 40% lacking access to clean cooking facilities. Global GDP is expected to treble by 2060, with two thirds of that growth coming from non-OECD countries. This GDP growth and increasing wealth levels will require vast amounts of energy.
- Emerging markets show significantly higher levels of energy intensity (units of energy used per unit of GDP) as they industrialize, and higher carbon intensity i.e. they emit more carbon per unit of GDP (and per capita), as they tend to use the cheapest, most readily available forms of power, which are often the 'dirtiest'.
- With most of the global GDP growth coming from emerging markets, a disproportionate amount of energy will be required, resulting in disproportionately higher emissions.
- Given the potential impact of emissions, the world is faced with an energy choice – either Action (mitigation or geoengineering) or Inaction (adaption) on climate change. These are examined in greater in detail in the chapters that follow.
- The likely total spend on energy (capex and fuel) over the next 25 years is actually remarkably similar on both an Action and Inaction scenarios — Citi's 'Action' scenario implies a total spend on energy of $190.2 trillion while our 'Inaction' scenario is actually marginally larger at $192 trillion.
- While in the Action scenario we spend considerably more on renewables (reducing in cost over time) and energy efficiency (effectively negative energy usage), the resulting lower use of fossil fuels lowers the total cost in later years.

Our Energy Choices

The world is faced with difficult, but enormously important choices about its energy future. Global primary energy demand is likely to grow by more than 30% over the next 20 years and how we adapt that demand given its linkage with GDP, and how we feed that hunger for energy will have enormous consequences for countries, economies, industries, and the world as a whole. While there are countless smaller decisions that will follow with either path, the choice can essentially be broken down into two paths:

We compare two scenarios – Inaction and Action and examine the effect these choices could have on global GDP and investment opportunities

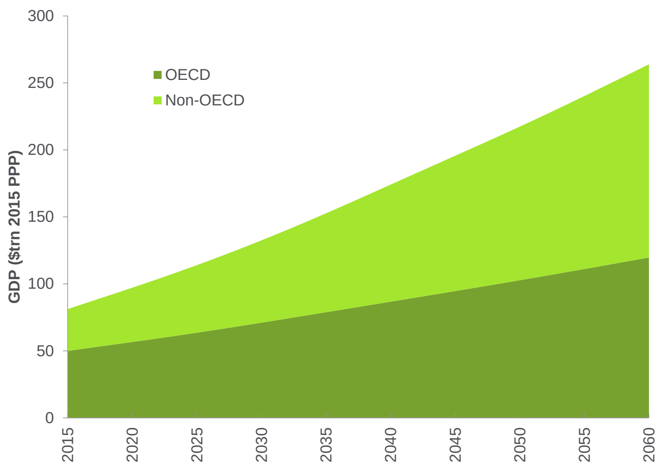
1. **Inaction** – We allow macroeconomics to drive demand for energy by ignoring the implications for emissions and feeding energy demand based purely on (often short term) economics and the immediate availability of fuel. To meet rapidly growing energy demand, this scenario will result in an enormous 'energy bill' for the world, and alongside this we must also consider the potential financial implications of climate change.
2. **Action** – We mold our energy future driven by a blend of emissions, economics, avoided costs and the implications of climate change. This requires an assessment of how much 'extra' we will spend on transforming the global energy mix to a low carbon energy complex, and what the other associated costs will be in terms of lost global GDP, stranded assets etc., offset against the avoided costs of climate change.

An Energy Hungry Planet

The IEA estimates that currently 1.3 billion people or 18% of the world's population do not have access to electricity, and 2.6 billion people (40%) lack access to clean cooking facilities. As wealth levels increase and the global economy develops, global energy demand is set to balloon over the coming decades, and the backdrop of its impact on the climate makes the choice of how that energy is generated, and indeed how much of it we use versus how much we save, of critical importance.

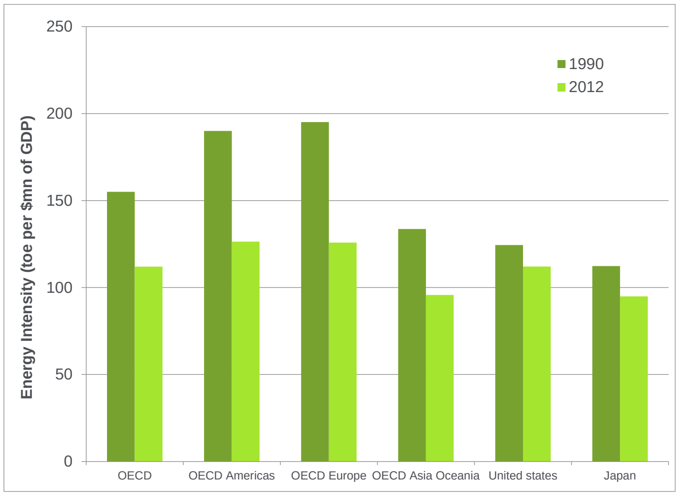
As Figure 15 shows, global GDP is set to increase from around $80 trillion today to around $260 trillion by 2060 (at current prices) — a threefold increase. Two thirds of that growth is scheduled to come from non-OECD economies.

Figure 15. Global GDP Growth Projections 2010-2060 by OECD and Non-OECD Grouping (Current Pricing)



Source: OECD, Citi Research

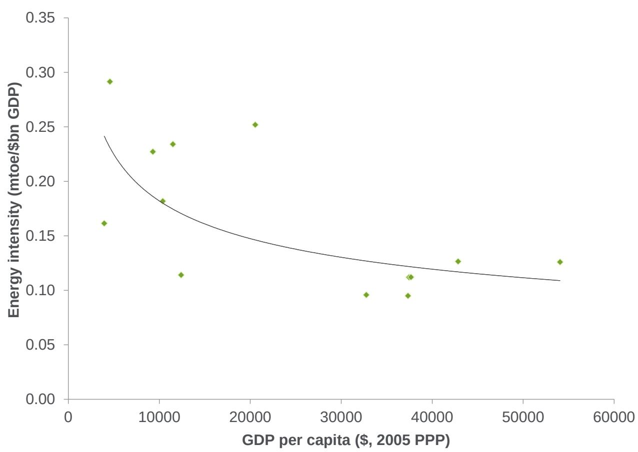
Figure 16. Energy Intensity Reduces Over Time as Nations Become More Wealthy



Source: OECD, IEA, Citi Research

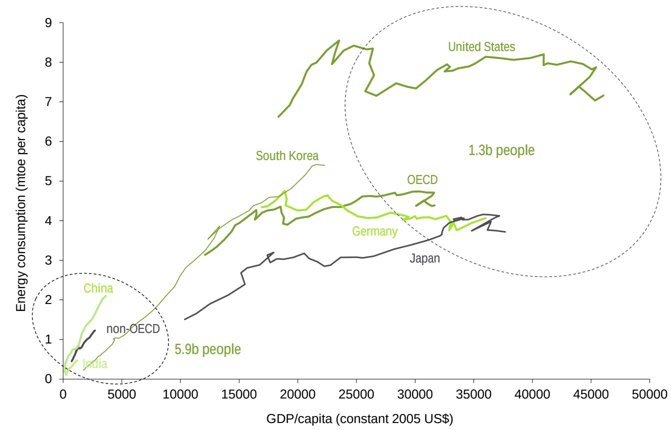
This GDP growth will require enormous quantities of energy, which is particularly pertinent when we consider that emerging economies show significantly greater levels of energy intensity, i.e. the amount of energy used per unit of GDP generated. The good news, as Figure 17 and Figure 18 show, is that as nations become wealthier, i.e. GDP per capita increases, energy intensity reduces mainly as these nations move towards a more service-based economy and become less focused on manufacturing, but also as efficiency increases.

Figure 17. Energy Intensity Reduces with Increasing GDP Per Capita



Source: OECD, IEA, Citi Research

Figure 18. Energy Consumption Per Capita Reduces as Wealth Increases



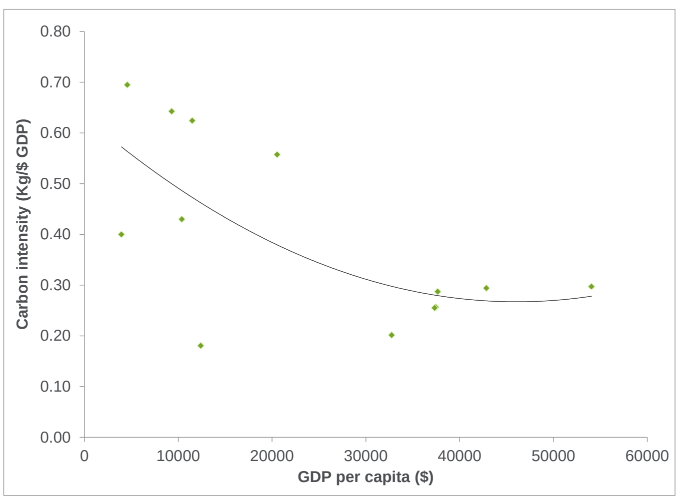
Source: OECD, BP, Citi Research

2/3rds of economic growth will come from emerging markets, which show higher levels of energy and carbon intensity per unit of GDP

Although a reduction in energy intensity is good news, the fact is that two thirds of global economic growth will come from emerging markets, which will require disproportionate amounts of energy to achieve that growth.

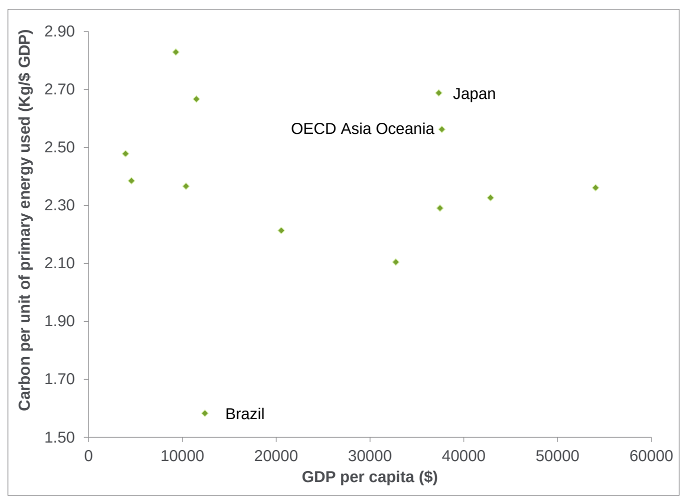
To add fuel to the fire, so to speak, emerging economies are often so power hungry trying to keep up with growth that there is a natural tendency to go for the cheapest, most quickly deployable forms of energy available (i.e. coal) which are often the 'dirtiest' in terms of emissions. This is not true across the board, as some developing economies have high proportions of hydropower (Brazil), while other developed nations which are blessed with significant fossil natural resources remain relatively high emitters (see Figure 20). However, this general truism combined with the higher levels of emerging market energy intensity mean that developing markets emit significantly larger quantities of CO_2 per unit of GDP generated than developed economies, as shown in Figure 19.

Figure 19. Carbon Intensity vs GDP Per Capita; Carbon Intensity Reduces with Increasing Wealth Levels



Source: OECD, IEA, Citi Research

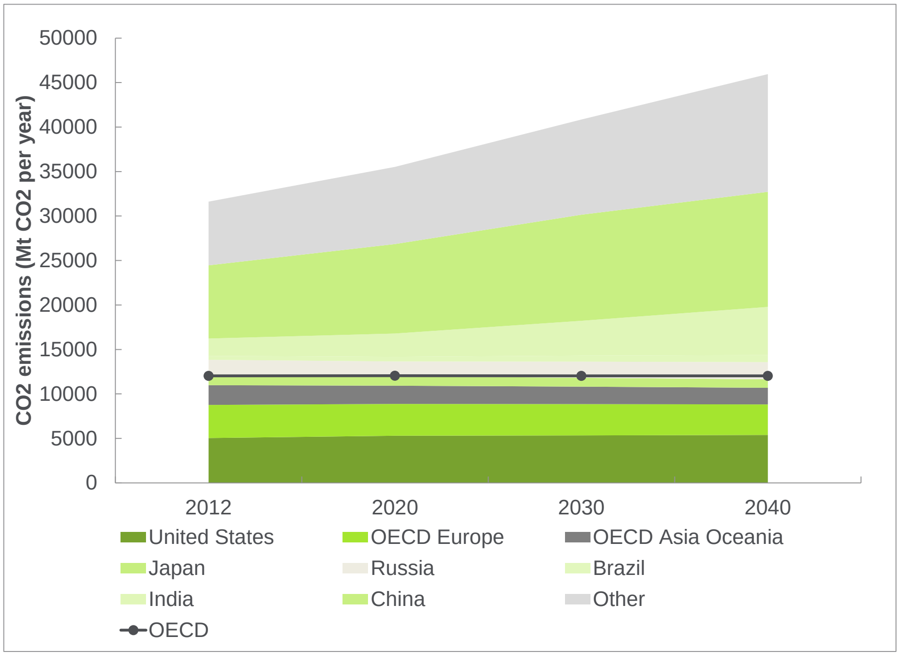
Figure 20. Emerging Markets Typically Use 'Dirtier' Fuels, though 2012 Trend is Skewed by Japan in the Wake of Fukushima



Source: OECD, IEA. Citi Research

More limited GDP growth with lower energy and carbon intensity in developed markets, combined with faster GDP growth and greater energy and carbon intensity in emerging markets, means that under current scenarios, carbon emissions would rise significantly in the coming decades, with effectively all of the growth in emissions coming from emerging or developing markets, as shown in Figure 21.

Figure 21. CO_2 Emissions by Country/Region Under 'Business as Usual' Scenario



Source: IEA, Citi Research

The Choice of Energy Path

There are three ways to reduce GHG emissions — adaption, geoengineering and mitigation, or a combination of the three. We concentrate on mitigation efforts to reduce energy-related emissions

The good news is that although close, we are not yet committed to the path of much higher emissions. There are three main ways that we can deal with the threat of climate change[9]:

- **Geoengineering:** Consists of a wide range of proposed methods of cooling the planet – some involve reflecting a portion of the sun's radiation back into space and others involve removing carbon dioxide from the atmosphere. It is an extremely complex subject and it is unclear if any of the proposed techniques are technically feasible, environmentally sound and socially acceptable. Given the infancy of this field, we have not examined this approach in detail, though would note that this is an area worthy of exploration potentially as part of our suggested increase in global R&D (discussed in chapter 'Making It Happen').

- **Adaptation:** Involves learning to cope with a warmer world rather than trying to prevent it. It is effectively a 'business as usual' approach, the costs and effects of which are examined in the chapters 'The Cost of Inaction' and under our Citi 'Inaction' scenario. Costs are likely to be significant, not just in terms of lost GDP, population displacement, agriculture etc., but in terms of the enormous investments required in infrastructure such as flood defenses. It is this latter area of costs — i.e. the costs of learning to live with a warmer climate — which are traditionally referred to as the costs of adaptation.

[9] Nordhaus (2013).

- **Mitigation:** Consists of action to reduce greenhouse gas emissions. In this report we concentrate on mitigation and the investment required in the energy sector for it to play its part in limiting warming to below 2°C relative to pre-Industrial levels, largely as this is easier to quantify with an associated greater level of certainty (though even this is still highly speculative).

Significant efforts to mitigate climate change can reduce the need for adaptation and the need for geoengineering, but one should not dismiss these other approaches completely, as global warming results from the accumulation of past long-lived GHG emissions, and therefore just reducing current GHG emissions might not be enough to reach a 2°C temperature increase limit. These approaches are therefore not mutually exclusive strategies, rather having synergies that can be exploited to enhance their cost-effectiveness.

We examine each of these options in turn over the following chapters

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Geoengineering

Mitigation is not enough. In order to achieve the climate policy goal of restricting the rise in global mean temperatures to less than 2°C above pre-Industrial levels will require some form of geoengineering.

Geoengineering is an umbrella term that covers a wide range of proposed techniques to counter climate change by deliberate large-scale interventions in the Earth's system. There are two main classes of techniques – Solar Radiation Management (SRM) and Greenhouse Gas Removal (GGR).

SRM involves reflecting a small proportion of the sun's radiation back into space. This could be achieved by introducing droplets of sulphuric acid into the upper atmosphere, which would act as tiny mirrors, or by brightening clouds. Such techniques could be fast-acting, cooling the planet quickly and could be cheap to deploy (compared to conventional mitigation), but the governance challenges of deploying such a technique would be immense and it would provide only a temporary fix. If you cease SRM, the temperature would bounce back up to where it would have been previously and if the level of greenhouse gases in the atmosphere is still increasing that bounce back would be extremely rapid and harmful. This so-called Termination Effect could in fact be terminal.

GGR involves removing CO_2 and other greenhouse gases from the atmosphere and storing them away so that they no longer affect the climate. This could be achieved by planting more forests or by developing machines that extract CO_2 from the atmosphere. All such techniques are likely to be expensive, but could provide a permanent fix. The governance challenges vary depending on technique, but in the main are likely to be less onerous than those associated with SRM.

You may not like the sound of geoengineering, but it is already assumed in the climate models that avoid dangerous climate change. The IPCC's RCP2.6 scenario is the only one that caps temperature rises below 2°C, but this is achieved only by assuming that emissions turn negative in the second half of this century – that GGR techniques will be deployed at a multi-billion tonne per year scale. There is a central incoherence in policymakers' efforts to avoid dangerous climate change — no such techniques exist and there is inadequate funding for research or incentives for industry to invest in developing such techniques. They seem to be willing the ends without providing the means.

Adaption: The Costs of Inaction

Highlights

- While the cost of adaption traditionally refers to the cost of living with climate change, such as increased spend on flood defenses, here we examine the additional costs to the world in terms of its impact on GDP.
- Climate change will have an impact on global GDP, and hence there is effectively a cost of inaction. Climate scientists use so-called “Integrated Assessment Models” (IAM’s) to estimate these impacts and costs.
- These IAM’s produce a wide range of expected impacts, the range of estimates being between 0.7% to 2.5% of GDP for a temperature increase of 2.5°C which is expected to be reached in 2060
- The cumulative losses to global GDP from climate change impacts (‘Inaction’) from 2015 to 2060 are estimated at $2 trillion to $72 trillion depending on the discount rate and scenario used. Lower discount rates encourage early action.
- If emissions continue to rise and therefore temperature continues to increase after 2060, the negative effect on GDP losses could become more than 3% of GDP with estimates ranging from 1.5% to almost 5%.
- Under an ‘Inaction’ scenario, the world would be locked to a high-emissions infrastructure and the damages could continue for more than a century.
- The highest impacts of GDP are foreseen in South and South East Asia, Africa and the Middle East.
- The estimated damages could be larger as these economic studies only measure those impacts that are quantifiable and largely concentrate on market or near market sectors. Other impacts such as tipping points, weather related events or catastrophic risks are not included in the studies.

Introduction

While 'global warming' is a general description of the potential effects, scientists believe that the biggest effects from climate change will actually be changes in rainfall patterns, ocean currents, growing seasons and everything else that depends on climate[10]. The impacts of climate change differ between one region and the next, with some regions likely to experience more frequent droughts, whilst others experience an increase in rainfall and potentially flooding. This could affect the availability and affordability of food and water, significantly impact poverty levels, health, mortality rates, and ultimately drive sizeable population displacement with all its associated implications.

Accordingly if the scientists are correct, the impacts of climate change could be significant, and would affect all of us. In economic terms, while little would remain unaffected, the sectors most obviously impacted by climate change include the energy, water, agriculture/food/fishery, and health sectors, not forgetting the insurance sector and banking/financial markets generally.

[10] Victor (2011)

The Cost of 'Inaction' on Global GDP

There have been several studies that have estimated the impact climate change could have on the global economy. Integrated Assessment Models (IAMs) are mostly used to calculate these damages as described in the box below. It is important to note that these welfare studies use different methods and different assumptions, which makes comparing them particularly difficult.

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Climate Economics - Integrated Assessment Models

Should climate action be more or less ambitious? What are the various advantages and disadvantages of different policy interventions? Who can, should and will pay? How ought the inherent risk and ambiguity be evaluated? What is the so-called social cost of carbon?

A standard and influential tool used by economists to answer these questions is the Integrated Assessment Model (IAM). There are different types of IAMs, but the types most commonly used by economists start with a baseline economic scenario that incorporates an assumed level of emissions. The models then consider the costs and benefits, at the margin, of reducing emissions to limit the damages that might result from climate change. In other words, the marginal costs of abating a tonne of carbon dioxide emissions are estimated and compared with estimates of the marginal social damage inflicted by that tonne. The latter is also referred to as the 'social cost of carbon' (SCC).

Policymakers are naturally interested in a single point estimate for the SCC that they can apply in government policy. However, there is a real risk that such a single point estimate is misleading. There is so much uncertainty that any single point estimate implies a false precision, as discussed below. Moreover, any estimate of social costs requires making choices that are ethically contentious, also discussed below under point two. Finally, the models used almost inevitably omit key considerations, implying that the point estimates may themselves be biased, as noted in section 3.

Nevertheless, such numbers are estimated and used. For instance, the United States Office of Management and Budget (OMB) and the EPA have conducted a joint analysis of the appropriate social cost of carbon for use in government policy, deriving a value of $37/t CO_2 (as of June 2015). This commentary considers the three key points to bear in mind when interpreting and using SCC estimates.

1. Scientific uncertainty about specific climate impacts

While the relationship between carbon dioxide emissions and increases in global mean temperatures are now fairly well understood, the uncertainty over the specific impacts in specific places at specific times remains substantial. Economists have, primarily for convenience, proxied the relationship between aggregate damages and temperature with a simple damages function. This expresses the fraction of GDP lost in a given year due to the relevant increase in temperature. Damages are often assumed, for convenience, to be a quadratic function of temperature increase. So it is assumed that damages increase smoothly as temperatures rise, with no abrupt shifts. There are, of course, other possible damages functions, and the evidence from the physical sciences suggests that functions with thresholds and triggers are far from ruled out.

Analysis of IAMs suggests that the carbon price can vary quite strongly on the specific response of ecosystems to temperature rises. As just one example, modelling by Ceronsky et al with FUND, a fairly standard IAM, suggests that if the thermohaline circulation (THC) were to shut down, the corresponding social cost of carbon (SCC) could increase to as much as $1,000/t CO_2. In short, the applicable social cost of carbon is very difficult to pin down because of the wide array of risks that could occur from our meddling with the climate system.

2. Value judgments cannot be avoided

Even if we were able to isolate and eliminate all scientific uncertainties in the chain of linkages between emissions, concentrations, temperatures and economic impacts, it would remain impossible to specify a single 'correct' estimate for the social cost of carbon. This is because a range of unavoidable social value judgments must be made in order to derive any estimate. These value judgments arise in a range of areas, but the four most contentious and important relate to valuing:

- **Impacts on future people**: The weight placed on impacts in the distant future, compared to impacts today, is reflected in the discount rate. This was one of the most contested parameters following the publication of the Stern Review, which used lower discount rates than previous studies, and in part for that reason concluded that the social cost of carbon was substantially higher.

- **Risk preferences**: Value judgments about risk preference are important too, given the risks involved in allowing the Earth's climate to heat. Higher aversion to risk tends to imply a higher social cost of carbon.

- **Inequality preferences**: It is expected that the impacts of climate change will fall more harshly upon the poor than the rich. How to value these effects strongly depends upon the assumed aversion to inequality.

- **Human lives**: Because climate change is expected to lead to a large number of deaths, the monetary valuation of a human life, if used, comprises a significant uncertainty in the overall estimate of the social cost of carbon.

These various value judgments have been debated at length by the economists and philosophers who work on the integrated assessment modelling of climate change. Now is not the place to rehearse those arguments in detail. However, it is worth noting that the use of market prices and market data – such as using market interest rates for government bonds as a proxy for the social discount rate – does not avoid these philosophical questions. The very decision to use the market is itself a (contested) philosophical choice.

3. Omission bias may lead to misleadingly low estimates

Finally, just as important as the scientific uncertainty and the inevitably of value judgments in SCC estimates is the concern that estimates emerging from economic IAMs may be systematically biased. The main source of concern is that, by definition, IAMs only model the effects that they are capable of modelling. The implication is that a wide range of impacts that are uncertain or difficult to quantify are omitted. It is likely that many of these impacts carry negative consequences. Indeed, some of the omitted impacts may involve very significant negative consequences, including ecosystem collapse or extreme events such as the catastrophic risks of irreversible melting of the Greenland ice sheet with the resulting sea level rise. Other consequences – such as cultural and biodiversity loss – are simply very difficult to quantify and are hence just omitted. While it is also likely that some omitted climate impacts are positive, it is highly probable that on balance such omitted impacts are strongly negative, leading to SCC estimates that are systematically too low and corresponding policy on climate change to be too weak. Indeed, the United Nations' IPCC assessment reports themselves accept that their own estimates should be viewed as being conservative, consistent with the prevailing culture of scientific enquiry.

Conclusion

Some scholars have concluded that given these limitations, IAMs are damaging or, at best, useless. It should certainly be openly and loudly acknowledged that estimates of the social cost of carbon are highly uncertain, subjective and potentially biased. Estimates should be accompanied with a corresponding warning of these weaknesses and advice to take any particular estimate with a grain of salt.

But not having models is not a solution either. Ignoring the intellectual challenges that are intrinsic to the economics of climate change does not make them vanish. Instead, economists need to do better, with much more transparent models – where value judgments and uncertainties are clear and can be played around with by policymakers and the general public – and where wide ranges are employed to communicate the sensitivities involved.

Along with transparency, a new generation of IAMs could focus our attention in more useful directions, away from short-term marginal changes and instead towards systemic, transformational change. This, rather than devising policy to balance central estimates of the social cost of carbon and central estimates of abatement costs, it may be better to seek interventions aimed at two objectives: (i) reducing the probabilities of very bad outcomes to very low levels, even if this involves relatively high cost; and (ii) increasing the probabilities of a positive transformational 'surprise' – for instance a cost breakthrough in clean technology – that could deliver very large social gains.

Determining a central estimate of the SCC does not prevent thinking about transformational change. However, an exclusive focus on the mean SCC tends to direct policy towards a set of interventions involving marginal, incremental changes to the existing system. Given the risks, and the potential benefits of a transition, incremental change is clearly far from enough. Instead, IAMs ought to help decision makers to consider major disruptive change. Far from being 'in the tails of the distribution', disruptive changes to our natural ecosystems and to our industrial ecosystems are now almost inevitable.

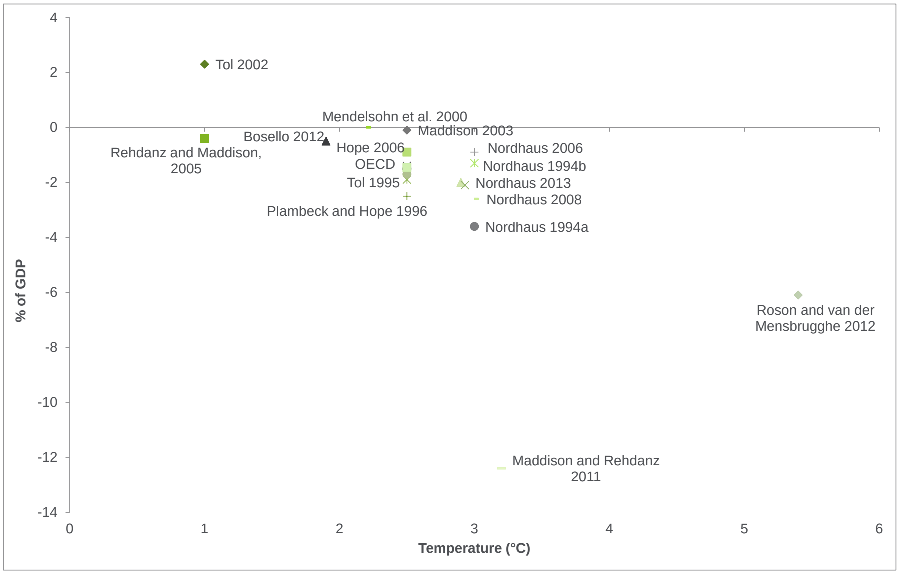
Generating an Aggregated View of IAM's

Of the many studies that have been written estimating the impact climate change could have on the global economy, one of the best known is 'The Economics of Climate Change' written by Lord Stern in 2006 which famously became known as the Stern Review. The main conclusion from the report was that that if we don't act now the overall costs and risks of climate change would be equivalent to losing at least 5% of global GDP each year 'now and forever' or 11% when one includes a rough estimate for other externalities such health and environmental effects that do not have market prices. Some of the impacts of climate change include access to water, food, health and the use of land and the environment. For example, a decline in crop yields especially in places like Africa could have a profound effect on future food production; ocean acidification as a direct result of increasing CO_2 emissions could impact marine ecosystems with possible effects on fisheries, whilst rising sea levels could result in millions of people being flooded each year due to an increase of warming of 3 or 4°C. Small islands in the Pacific and Caribbean and large coastal cities such as Shanghai could all be affected by sea-level rise.

Climate economists agree that an increase in temperature would have a negative effect on global GDP

Stern has been criticized by academics amongst other things for his use of a low discount rate (average 1.4%) — a topic which is much discussed in climate change economics. Other studies have also been undertaken to assess the aggregate damages from climate change for different levels of warming. The majority of these studies agree in principle that an increase in temperature would have an impact on the global economy ranging from 0.9 to 2.5% of global GDP loss for a temperature increase of 2.5°C. This loss increases to 6.4% for a temperature increase of over 5°C (refer to Figure 22 below). These costs are not one-time but are rather incurred year after year because of permanent damage caused by increased climate change

Figure 22. Aggregate Estimated Potential Climate Change Damages to Global GDP



Source: Arent et al. 2014[11] Citi Research

Global GDP losses from climate change inaction are estimated from 0.7% to 2.5% in 2060.

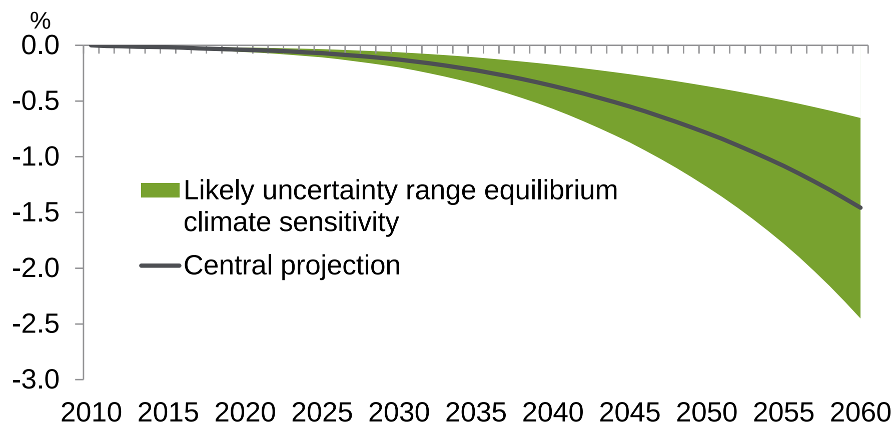
The OECD estimates that global GDP losses from climate change inaction range from between 0.7% to 2.5% in 2060 as shown in Figure 23 below. These calculations are well within the estimates of other studies as described above. The losses are calculated for only for a number of related sectors such as agriculture and health. Other climate change impacts such as water stress or extreme weather events which are not included in this analysis would also have large economic impacts.

[11] Arent, D.J., R.S.J. Tol, E. Faust, J.P. Hella, S. Kumar, K.M. Strzepek, F.L. Tóth, and D. Yan, 2014: Key economic sectors and services – supplementary material. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability.Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of theIntergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea,T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken,P.R. Mastrandrea, and L.L. White (eds.)]. Available from www.ipcc-wg2.gov/AR5 and www.ipcc.ch.

Assumptions of Climate Change Damage Estimations

In its scenario, the OECD assumes a 2.9% average global growth rate of GDP. Global greenhouse gas (GHG) emissions (excluding emissions from land use, land use change and forestry) are projected to rise from roughly 45 GT CO_2e in 2010 to just over 100 GT CO_2e in 2060. Concentrations of carbon in the atmosphere (CO_2 only) rise from 390 ppm to 590 ppm in the same time frame. In its central projection scenario, it calculates that a 2°C temperature increase is reached in 2055, and the associated global GDP annual loss amounts to 1.1%. Temperature increases to more than 2.5°C by 2060. The model calculates the economic impacts from sea-level rise, health, ecosystems, crop yields, tourism flows, energy demand and fisheries but does not include economic damages from extreme weather events or catastrophic risks.

Figure 23. Climate Change Impact on GDP



Source: Braconier et al, (2014)[12]

It is also important to note that the damages to GDP calculated above only refer to global GDP losses up to 2060, however GDP losses may reach 5% if greenhouse gas emissions continue rising after this period. Also the economic damages from climate change inaction do not take into account non-market impacts, tipping points and other catastrophic events (discussed in more detail at the end of the chapter). The damages and costs relate to an increase or reduction of greenhouse gas emissions from the energy-sector which represent approximately two thirds of current emissions. The damages and costs from greenhouse gas related to changes in land use and land cover and from other sectors are not included here. What is important is that emissions between now and 2060 (under an 'Inaction' scenario) would commit the world to a high-emissions infrastructure and the damages would continue for more than a century.

[12] Braconier H, Nicoletti G, Westmore B, (2014), 'Policy Challenges for the next 50 years', OECD Economic Policy Paper, July 2014, No. 9, Paris

Putting a Value on the Lost GDP

The use of discount rate plays a very important part in estimating future liabilities.

In the context of global GDP which is currently around $80 trillion and expected to more than triple by 2060, the sums of money potentially at stake are hard to comprehend, especially as they are annual and cumulative. Figure 24 shows the cost of liabilities or damages to global GDP from inaction to climate change which differ according to the discount rate that is being applied and the uncertainty level. The use of discount rate in climate change economics has been debated and there are very different views on what is the best discount rate to use (see 'The Discounting Debate' below).

Figure 24. The 3 Scenarios of the Potential Costs of Climate Change, Showing the Significant Effect that Different Discounting Rates Have

		NPV of 'Lost' GDP	
Discount Rate	Low $ Trillion	Central $ Trillion	Upper $ Trillion
0%	-20	-44	-72
1%	-14	-31	-50
3%	-7	-16	-25
5%	-4	-8	-13
7%	-2	-5	-7

Source: Citi Research

The Discounting Debate

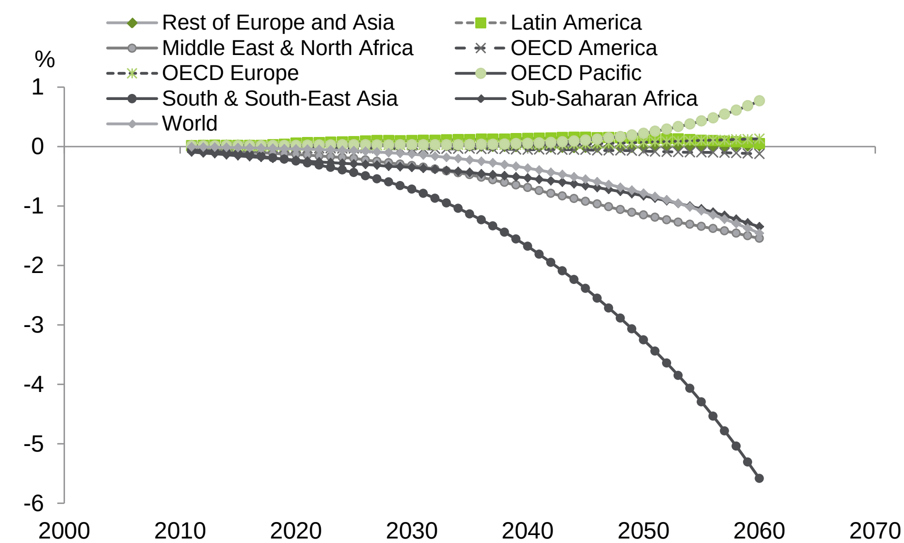
The rate at which future benefits and costs are discounted relative to current values often determines whether a project passes the benefit-cost test. This is especially true of projects with long term horizons, such as those to reduce greenhouse gas emissions. Whether the benefits of climate policies (which can last for centuries) outweigh the costs (many of which are borne today) is especially sensitive to the rate at which future benefits are discounted. Economists traditionally advocate that the discount rate should be primarily determined by the cost of capital; however others hold that it is unethical to discount the welfare of future generations and therefore a lower discount rate should be used to calculate the present value of future climate damages. Figure 24 shows the climate damages based on different discount rates − a low discount rate encourages early action primarily because future damages count for so much. Which is the correct discount rate to use is difficult to determine, and there is also a debate on whether the liabilities vs. cost of avoidance should be discounted at different rates, or whether we should a discount rate that reflects the actual market opportunities that societies face.

Economic Damages in Different Regions

South and South East Asia, Africa and the Middle East could experience the largest impacts on climate change

The extent of the economic damages from climate change is likely to differ substantially between different regions and different sectors. The highest impacts of GDP are foreseen in South and South East Asia, Africa and the Middle East, whereas countries in the upper Northern hemisphere such as Russia may be able to reap some economic benefits from climate change (Figure 25). One of the conclusions of the OECD studies described above was that climate impacts, to a large extent, are concentrated in vulnerable and high-populated regions. However it is important to look at the diagram below with some caution as economies do not operate in insolation, and the climate change impacts in one region could affect the economies in other regions. Impacts could also differ within one country or region. For example, even though the impact on the average national GDP would not be felt much in OECD Europe countries, it does not mean that these countries would not see any negative impacts. The relative gain in GDP for OECD Pacific countries occurs because the major economies in South and South East Asia would observe large losses in agriculture production. However extreme droughts are likely to happen in Australia which could negatively affect the OECD Pacific region's average GDP. Also some countries would be able to adapt more clearly to some of these impacts, by for example importing more food, however other regions would lose their competitive advantage in certain areas to other regions. Annual GDP is also an imperfect measure of the total economic costs of climate change as it does not include the wider-impacts on well-being.

Figure 25. Regional Economic (GDP) Impact of Climate Change to 2060 (Central Projection)



Source: Bracconier et al. (2014)

Co-Benefits from Reducing Emissions

There are also several co-benefits in reducing emissions including improving air quality standards, increasing energy security and reducing water use

There are also co-benefits from reducing greenhouse gas emissions which should be calculated when taking into consideration the liabilities and costs of avoiding of climate change. Reducing emissions can decrease fossil fuel imports for certain countries and therefore enhance energy security. Fossil fuel importers would spend less in our 'Action' scenario than in the 'Inaction' scenario (described in detail later). Reducing GHG emissions can also help improve air quality standards in many cities. In 2010, the cost of the health impact of air pollution (which is partly attributed to electricity generation and transport) in China and India was estimated at $1.4 trillion and $0.5 trillion respectively. Renewable resources such as solar and wind need little or no water resources when compared to fossil fuel power generation which needs water for cooling purposes. This could make a huge difference to water scarce countries that rely on freshwater for cooling in power generation.

Non-Market Impacts and Tipping Points, a Point of Caution

The loss to GDP maybe even higher if tipping points and non-market impacts are included in the analysis

Integrated assessment models used to estimate climate damages of inaction only measure those impacts that are quantifiable and largely concentrate on market or near market sectors such as agriculture, health etc.[13] However these studies omit other impacts which are difficult to measure such as tipping points, catastrophic risks and extreme weather events.[14] According to the IPCC 'no estimate is complete', however most experts believe that excluded impacts such as non-market effects are on balance all negative. These economic impacts are difficult to estimate and lie well outside the conventional market place, however they could have a substantial impact on a regional economy. For example, according to the World Bank, the economic damages and losses due to the floods in Thailand in 2011 was estimated at $46 billion, not to mention the enormous loss of life. It is not known with any certainty whether this event was triggered by climate change, but this shows the regional impacts an increase in catastrophic weather events could have on a region. Large tipping points on the other hand can occur when small climate changes trigger a large impact and can pose a systematic risk, such as the melting of the Greenland ice sheets. These risks increase with temperature rise and can induce shocks to both climate and the economic systems.

Is GDP the right measure to use?

There is also a discussion on whether annual GDP loss from climate change damage is the right metric to use. GDP measures only the flow of production, income and expenditure and does not include the stock of assets or wealth. As a result it does not record the deterioration in a country's natural resources which could ultimately be affected by climate change. Clearly including these risks would increase the potential financial costs from climate change (see Citi GPS: THE PUBLIC WEALTH OF NATIONS for more information).

[13] Nordhaus (2013)
[14] Delink et al. (2014)

Mitigation: The Costs of Action

Highlights

- Action to mitigate climate change inherently involves a cost. Hence we need to be either incentivized into taking a low carbon path, or penalized for not doing so. Action can take differing forms, most notably either legislation to force change, or via the creation of economic instruments such as putting a 'price' on carbon.

- If we compare the difference in cost between adopting a low carbon future and business as usual, we can derive a cost of mitigation. There are many differing methods of doing so, with some such as the IEA's long standing approach focusing purely on capital investment, while other approaches such as the one that we have adopted look at the total spend on energy thereby capturing fuel costs. Both approaches have their advantages and disadvantages, and we examine these, and highlight where our scenarios differ from those of the IEA.

- Over the next few chapters we examine the implications of Citi's 'Action' scenario which goes down a low carbon route, with a focus on the electricity sector as the largest current emitter and fastest growing area of energy usage globally. We examine the potential costs of transforming the energy mix in electricity production and its impact on emissions, and link this to an implied cost of carbon purely for the electricity sector, discussing how that might vary over time.

- What is perhaps most surprising is that looking at the potential total spend on energy over the next quarter century, on an undiscounted basis the cost of following a low carbon route at $190.2 trillion is actually cheaper than our 'Inaction' scenario at $192 trillion. This, as we examine in this chapter, is due to the rapidly falling costs of renewables, which combined with lower fuel usage from energy efficiency investments actually result in significantly lower long term fuel bill. Yes, we have to invest more in the early years, but we potentially save later, not to mention the liabilities of climate change that we potentially avoid.

- A low carbon route essentially involves investing more heavily in low emissions technologies such as renewables, investing less in fossil fuels, in particular coal in power and oil in transport, and investing significantly more in energy efficiency to reduce overall energy usage. We examine the implications of carbon for the integrated energy cost curves first derived in the original Energy Darwinism report, and in particular examine the implications of this potential mix-shift in terms of stranded assets.

- By comparing the cost of mitigation to the avoided 'liabilities' of climate change, we can derive a simple 'return on investment'. On a risk adjusted basis this implies a return of 1-4% at the low point in 2021, rising to between 3% and 10% by 2035. While not spectacular returns, against current low yields (and given the potential consequences), it represents a relatively attractive option.

- With a limited differential in the total bill of Action vs Inaction (in fact a saving on an undiscounted basis), potentially enormous liabilities avoided and the simple fact that cleaner air must be preferable to pollution, a very strong "Why would you not?" argument regarding action on climate change begins to form.

Different Types of Action

A simple reason why atmospheric concentrations of greenhouse gases has grown is that they have been put there as a result of our using historically the cheapest, easiest, or most readily available solutions to a requirement, such as energy. To look at it another way, adopting a lower carbon path is (at least superficially) more expensive, otherwise all things being equal we would logically have gone for a cleaner option.

Accordingly, to change our behavior entails a cost, and hence will require some form of mechanism to offset that cost, either involving incentives or penalties. There are two main ways to encourage a move to a low carbon economy:

1. **To enact legislation to force change**: an example of this is the new US legislation which aims to cut carbon emissions from power plants by 30% or the US Corporate Average Fuel Economy (CAFE) which encourages fuel efficiency improvements in the transport sector.

2. **To develop economic instruments**: that provide an incentive (or avoided penalty) to switch to low carbon technologies and fuel such as quotas, carbon pricing and tradable permits. Carbon pricing is one such economic instrument which will effectively put a price on GHG emissions both to provide an incentive to reduce them and also to minimize the costs of abatement by efficiently allocating capital to the most cost effective abatement options first. It also prices the externalities of GHG emissions encouraging a move to low carbon fuels if carbon is adequately priced.

The next two chapters examine both of those mechanisms, in the form of deriving a cost of carbon for the power sector, and an examination of the effects of legislation relating to energy efficiency, mainly in the transportation market.

Assessing the Incremental Cost of Action

There are many different approaches to estimating the cost of action to mitigate climate change, each with their own benefits and pitfalls. There are equally as many global integrated energy models which are used by the investment community, corporates and governments, which highlight differing energy mixes going forwards.

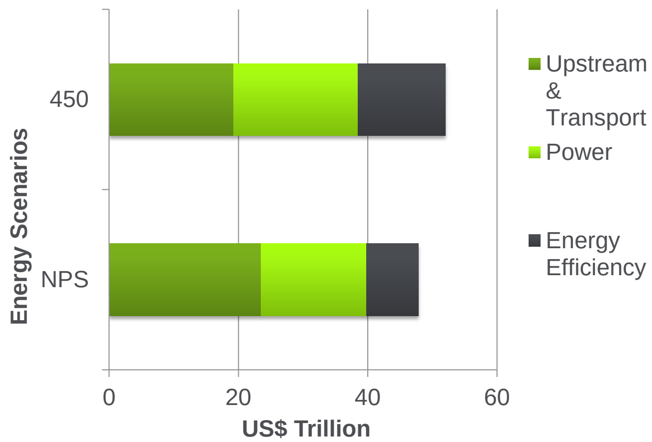
Of the numerous global energy investment scenarios available, perhaps the most comprehensive is that put forward by the IEA. We examine this scenario, before moving on to discuss the benefits and limitations of this approach, and to highlight where our own ‘Action’ and ‘Inaction’ scenarios differ in their approach and findings.

The IEA Scenarios and Where We Differ

$53 trillion capex investment is needed to invest to have a chance of limiting temperature increase

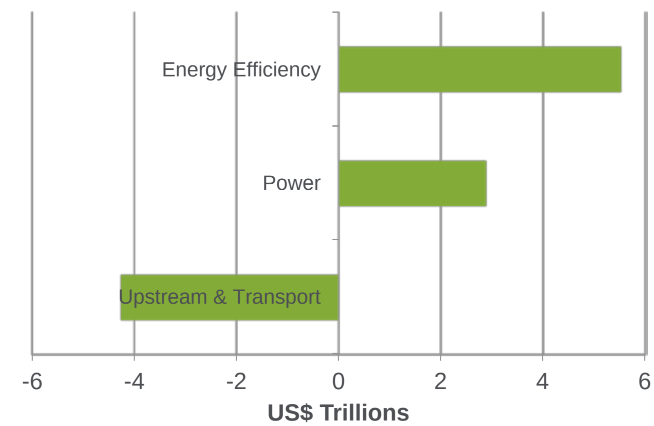
The IEA bases its analysis on capital investment using its own integrated global climate and emissions model which it has been publishing and refining for more than 20 years; accordingly it is worthy of significant respect. The IEA estimates that the total capex investment required for energy (and efficiency) from 2014 to 2035 is $48 trillion in its central energy scenario (the so-called 'New Policies Scenario' or NPS scenario), increasing to $53 trillion for a 50% chance of meeting a 2°C temperature increase target (the '450 scenario'), as shown in Figure 26. The ‘450 scenario’ is so called as it lays out a scenario which would limit greenhouse gas concentrations to 450ppm, the level generally accepted that would give the world a 50% chance of limiting climate change to 2°C or less. The IEA’s ‘New Policies Scenario’ lays out an energy mix where current and signaled emission reduction commitments are enacted, and replaced on expiry; this is effectively the IEA’s base case. The ‘Current Policies Scenario’ assumes that as current policies expire, they are not replaced or extended.

Figure 26. Cumulative Investment Required Under the IEA's NPS and 450 Scenarios



Source: IEA (2014a), Citi Research

Figure 27. Delta in Investment by Energy Segment between the IEA's 450 and NPS Scenarios

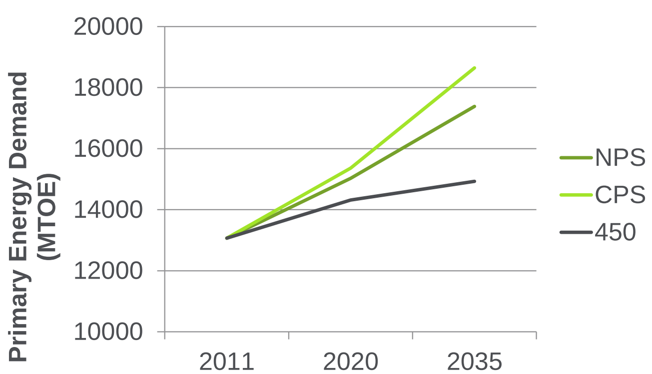


Source: IEA (2014a), Citi Research

As Figure 26 and Figure 27 demonstrate, the energy sector's transition in the IEA's '450 scenario' requires not only more capital investment but a notably different allocation of capital. Investment in power generation and energy efficiency in the '450 scenario' increases by $2.9 trillion and $5.5 trillion respectively, whilst investment in upstream, transport and refining of fossil fuels decreases by $4.2 trillion when compared to the NPS scenario. Much of the incremental investment in power generation is allocated to the deployment of renewables, whilst over $3 trillion of the incremental investment in energy efficiency is allocated to the transport sector.

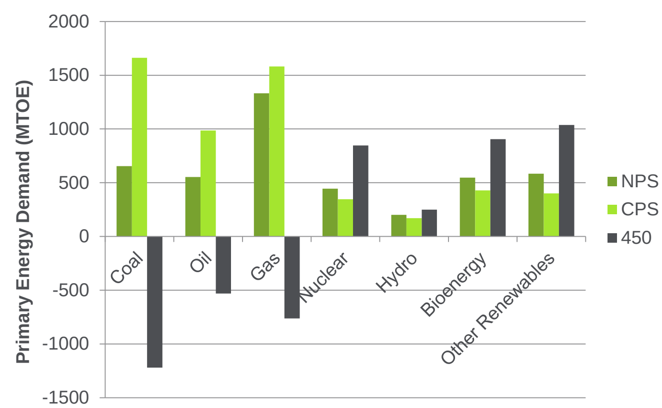
In terms of fuel mix, Figure 28 and Figure 29 below present the primary energy demand and changes therein from 2011 in 2035 under the IEA's three scenarios.

Figure 28. Primary Energy Demand Under Three Scenarios



Source: IEA (2013)

Figure 29. Change in Primary Energy Demand from 2011 (in 2035)



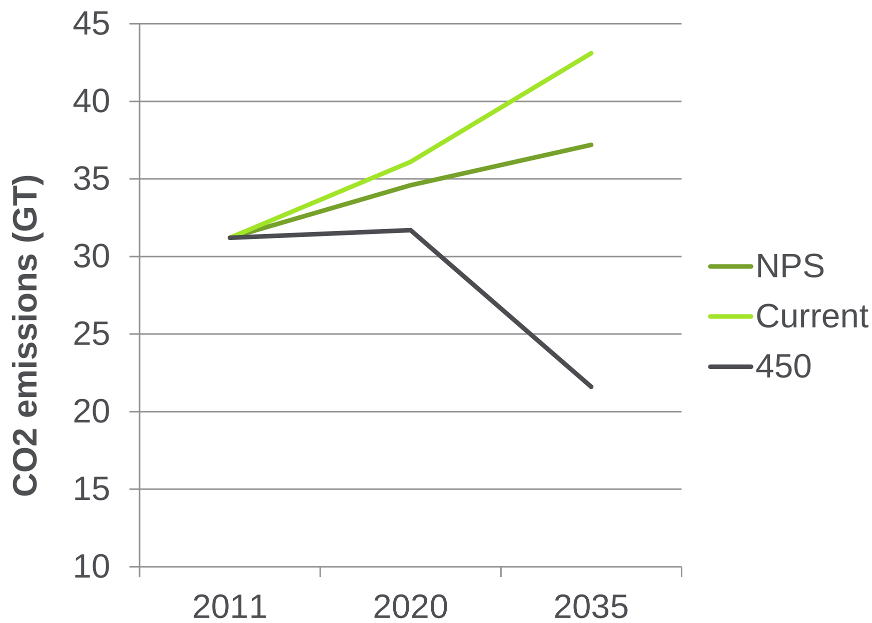
Source: IEA (2013), Citi Research

As one can see from the diagram above, the '450 scenario' reduces the primary demand for fossil fuels and increases the demand for nuclear, bioenergy and other renewables.

Impact on Emissions

In meeting the '450 scenario', energy-related emissions would need to peak by 2020 and decline to around 22GT in 2035 as shown in Figure 30 below. The cumulative emission gap between the NPS and the '450 scenario' is around 156GT of CO_2. The largest reduction in emissions occurs in power generation followed by the transport and industry sectors (IEA, 2014).

Figure 30. CO_2 Emissions in Different Energy Scenarios



Source: Citi Research

Deriving a Return on Investment

One of the advantages of examining purely capex alongside the potential damages of climate change, is that one can derive a 'return' on that investment in terms of avoided costs in a way that a holistic energy spend approach cannot.

Figure 32 shows the NPV of the energy capex spend of going down a low carbon route with a 50% chance of limiting temperature increase to 2°C (the IEA's '450 scenario') and the energy capex spend for a scenario which increases temperature by over 3°C (the NPS scenario).

Figure 31. The 3 Scenarios of Potential Cost of Climate Change in Terms of NPV Lost to GDP, at Different Discount Rates

	NPV of 'Lost' GDP		
Discount Rate	Low $ Trillion	Central $ Trillion	Upper $ Trillion
0%	-20	-44	-72
1%	-14	-31	-50
3%	-7	-16	-25
5%	-4	-8	-13
7%	-2	-5	-7

Source: Citi Research

Figure 32. NPV of the Differential Cost Between the IEA's NPS (Business as Usual) and 450 (Low Carbon) Scenarios, Using Different Discount Rates

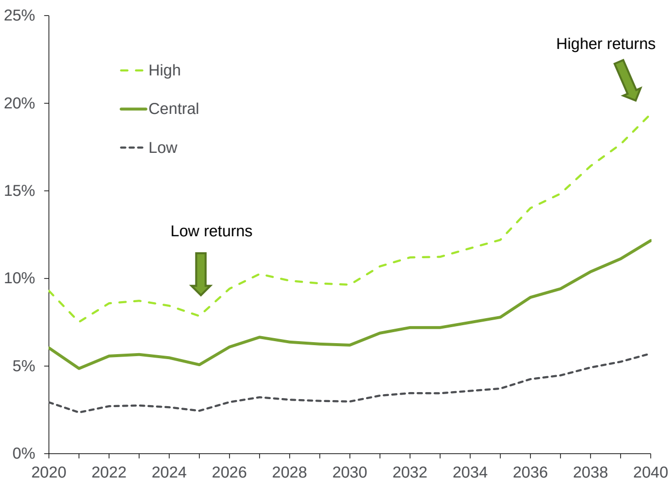
Discount Rate	NPS $ trillion	450 $ trillion	Difference $ trillion
0%	48	53	4.8
1%	44	48	4.2
3%	36	40	3.4
5%	31	34	2.7
7%	27	29	2.3

Source: Citi Research, IEA

Figure 31 and Figure 32 demonstrate that at low 'societal' discount rates, climate change damage costs outweigh the incremental cost of adopting a low carbon path. It is notable that it is only with relative high discounting rates on the damages that the cost would seem hard to justify. Given the inter-generational debate we see some merit in using a much lower 'social' discount rate than might be applied to usual investment decisions. Conversely, when comparing the potential costs and benefits of Action, it would seem disingenuous to not discount the liabilities (in terms of potentially avoided costs), but to then compare this to a discounted cost of Action.

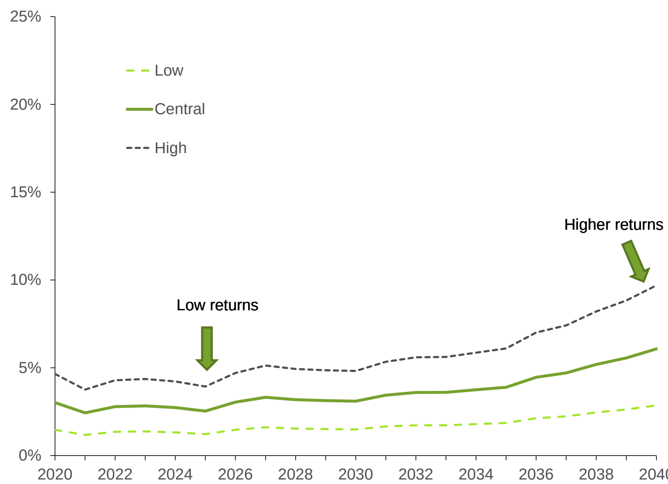
In this section we compare the incremental cost of following a low carbon path with the estimated value of reduced damages in the future. It is also useful to look at these investment choices in terms of returns as one would any normal investment choice. Figure 33 and Figure 34 show the implied return in terms of avoided liabilities of inaction, with reference to the incremental undiscounted cost of Action ($4.8 trillion). The numerator used in the calculation is the incremental 'saved' GDP in each year, thereby giving an implied annual 'return' on that incremental investment figure. Figure 34 then takes these implied returns and halves them; this would seem appropriate given that the IEA's '450 scenario' is derived to offer a 50% chance of avoiding a temperature increase of more than 2°C, i.e. the return is effectively risk adjusted.

Figure 33. Implied Return of Incremental Avoided Costs on Annual Spend



Source: Citi Research

Figure 34. Risk-Adjusted Return of Incremental Avoided Costs on Annual Spend, to Reflect 50% Chance of Avoiding Climate Change



Source: Citi Research

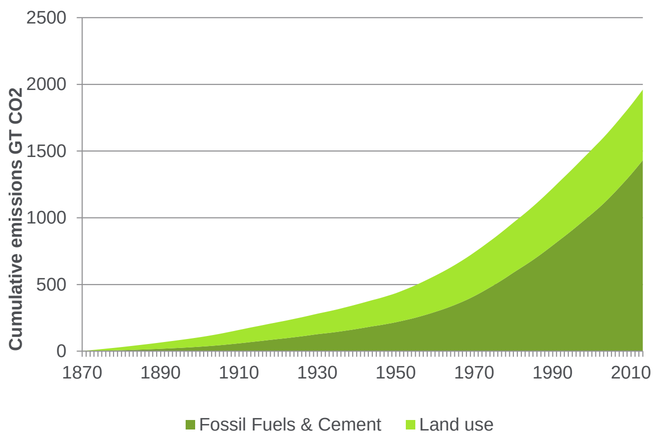
As avoided losses increase, the returns increase to between 3-8%

As the figures show, while the risk adjusted returns are limited at lows of 1-4% depending on the scenario, as the avoided losses increase, those returns increase dramatically to between 3-10%. While still not enormous, in the context of current yields, and certainly in the context of the potential implications of inaction (and that later remedies are significantly more expensive), the low carbon route begins to look relatively compelling. Given that there is a reasonable (though not spectacular) return, and on the basis that simplistically cleaner air must be preferable to pollution, the "Why would you not?" argument again comes to the fore — an argument which becomes progressively harder to ignore over time. Coupled with the fact the total spend is similar under both action and inaction, yet the potential liabilities of inaction are enormous, it is hard to argue against a path of action. Admittedly some industries will suffer, others will benefit, and the effects will be felt differently around the world; the challenge therefore is to get policymakers to think holistically and to act accordingly, and to allow the funds to flow in the right directions (as examined in the final chapter of this report, "Making it Happen").

Investment in Power Generation

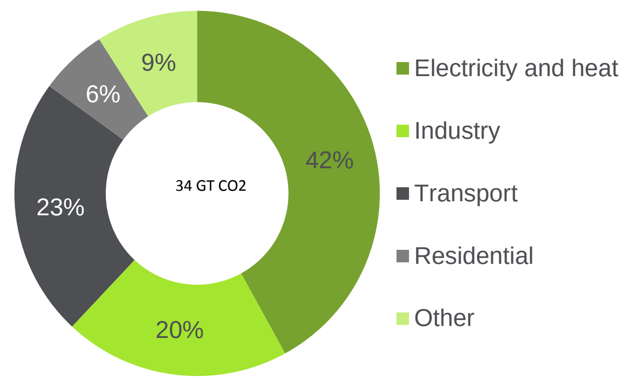
Out of all greenhouse gas emissions (measured in CO_2 equivalents for comparative purposes) energy-related CO_2e emissions made up the majority of greenhouse gas emissions estimated at 65% in 2010. Of those emissions, 90% were from the combustion of fossil fuels.

Figure 35. Cumulative CO_2 Emissions from Energy and Land Use



Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Figure 36. Percentage of Annual Energy-Related Emissions by Sector (2010)



Source: IEA (2014), Citi Research

Of those energy related emissions, by far the largest part (42% in 2013) were from the power sector, itself the largest single greenhouse gas emitter in the climate change debate. Transport was responsible for a further 23%, meaning that combined with power, they accounted for two thirds of emissions from energy, which itself was two thirds of total emissions.

We focus on the electricity sector in detail as it is the largest emitter

While we recognize that the electricity market is only part of the puzzle to combat climate change, given that it is the largest single greenhouse gas emitter in the climate change debate, policy action in the power market would make potentially the most meaningful impact to greenhouse gas emissions, if designed and implemented appropriately. Hence we have focused our attention in this report on the costs associated with transforming the electricity market, what impact these transformations have on the 'carbon budget' and the dynamics of this transformation.

We have constructed two energy scenarios which form the basis of the analysis in this report:

- **Citi's 'Inaction' scenario**: An energy mix out to 2040 which is essentially a business as usual scenario, which assumes the current energy mix remains relatively constant and that there is no investment in energy efficiency. While there obviously *is* current investment into energy efficiency we are trying to assess the incremental amount which is being spent on following a low carbon future to examine the 'affordability' of preventing climate change, and hence a 'zero' baseline is necessary.

- **Citi's 'Action' scenario**: In constructing this scenario to 2040 we have focused the bulk of our analysis on the power sector, as the largest single emitter in the energy segment, (an approach which is outlined in more detail in the next chapter). We assume significantly greater levels of renewable deployment than the IEA's '450 scenario' and that costs reduce faster. Moreover, our approach to assessing costs differs materially. Efficiency, largely in transport, is also examined in a separate chapter. In our assumptions for the transport and industry segments of energy we have adapted the IEA's assumptions, applying assumptions of our own and altering time frames. Having focused on the power sector in this report, both of these areas we intend to be subject of more detailed follow-on reports.

Levelized Cost of Electricity: A Different Measure of Cost

Given the existing rigor of the IEA's capex-based approach, we have chosen to adopt a slightly different approach to assessing the overall likely costs of energy to the global economy.

We take into consideration not only capex spending but also include the overall avoided fuel costs of moving to a low carbon future.

Instead of estimating the capital cost requirements to enable a transition in the global energy market (which has already been done) we focus our Citi analysis on the overall costs of energy procurement. In the power sector where we focus our analysis, we therefore use a levelized cost of electricity (LCOE) approach which captures both the fuel and capital costs over the useful life of an asset. Effectively the LCOE answers the question: "At what price does a certain power plant have to sell electricity to break even for a plant operator?"

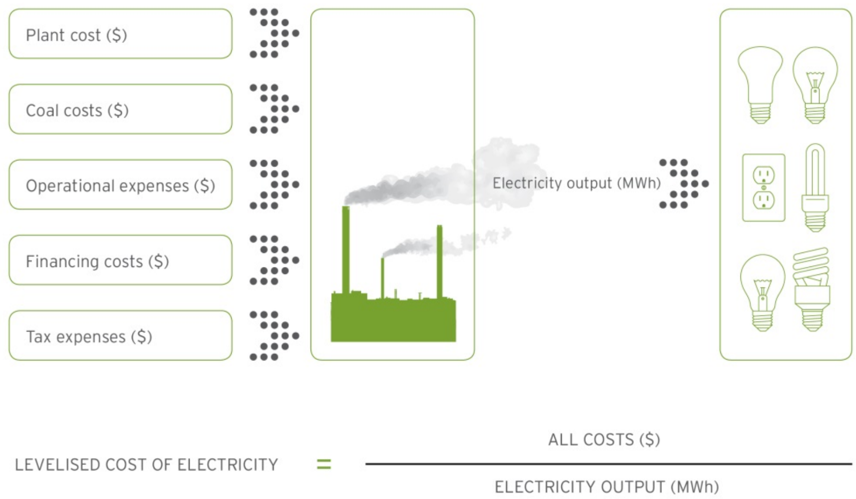
Examining just capex spend in the energy transformation runs the risk of missing the avoided cost in terms of future reduced fuel demand. While this is arguably partially captured by lower required upstream capex in fossil fuels, we believe that adopting an LCOE approach to the electricity sector therefore provides a more holistic view. No approach is perfect however; an LCOE approach has its own drawbacks in terms of assumptions on commodity prices, regional differentials etc., but we believe it can complement capex-based analysis if used in conjunction, and more it allows different types of analysis such as comparing the total amounts 'spent' on energy to be compared to for example GDP levels. The benefits and pitfalls of both approaches are examined later.

Why is LCOE Useful to Compare Different Technologies?

Different technologies have different cost profiles. While renewable energy costs more to build relative to a unit of energy produced, this ignores the fact that once built, renewables plants incur limited costs compared to fossil fuels, as they consume no fuel. The useful life of a coal-fired plant is about 40 years whilst for a solar photovoltaic (solar PV) plant it is 25 years. This makes the usefulness a dollar of capex spent on a coal-fired plant difficult to compare to a dollar spent on a solar PV plant.

As the levelized cost of electricity captures all costs of electricity generation over the lifetime for each technology it is widely used to compare cost competitiveness of different fuel types.

Figure 37. Levelized Cost of Electricity



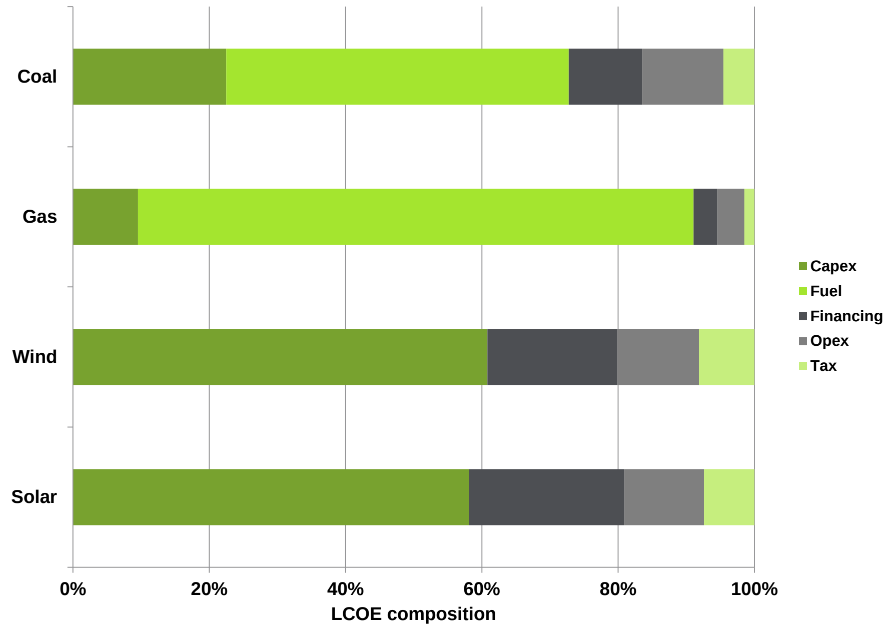
Source: Citi Research

The Benefits of an LCOE Approach (1): The Difference in Cost Breakdown

Capex makes up the majority of the costs for renewables, whilst for gas 80% of the costs relate to fuel

The cost composition between different technologies can vary quite markedly. For renewable energy, upfront capital expenditure on equipment makes up the majority of costs: around 60%. As renewable energy projects are generally levered with debt, financing costs also play an important part in the cost equation. On the other hand, coal and gas-fired plants are more sensitive to fuel costs. This is particularly extreme for a gas-fired plant, for which fuel costs make up over 80% of its levelized cost of generation. Variations in gas price can therefore cause large swings in the competitiveness of gas-fired plants. For coal-fired plants the economics are less biased towards fuel cost while on the other hand upfront construction costs make up 25% of total cost of electricity produced. Figure 38 shows a full cost breakdown of all technologies considered.

Figure 38. Levelized Cost of Electricity Breakdown for Different Generating Types



Source: Citi Research

As Figure 38 highlights, capex as a proportion of the overall cost of a unit of electricity generated by different technologies varies dramatically, from around 10% for a combined cycle gas turbine (CCGT), up to around 60% for both wind and solar; conversely, fuel makes up over 80% of gas LCOE, versus zero for wind and solar.

Accordingly, examining capex on a standalone basis runs the risk of overstating the cost of renewables, and understating the total cost of conventional generation technologies. This is particularly true if any form of discounting is used, as the bulk of the costs for renewables are upfront, whereas for gas they would be backloaded.

The Benefits of an LCOE Approach (2): The Pace of Change

Given the rapid increase in the pace of substitution in energy markets over the last two years, the main focus of the original Citi GPS: ENERGY DARWINISM report was to show how dangerous assumptions on capex can be when the pace of change in an industry is so rapid, and the rate of evolution so fast.

One of the key theories from the original energy Darwin report was highlighting these differing rates of cost evolution of different generation technologies. Solar in particular was exhibiting learning rates in excess of 20% (i.e. the cost of a panel would fall by >20% for every doubling of installed capacity), wind at 7.4%, gas was evolving via the shale revolution in the US, while nuclear was becoming more expensive, and liquefied natural gas (LNG) had also increased in cost by around 10% per annum over the last decade.

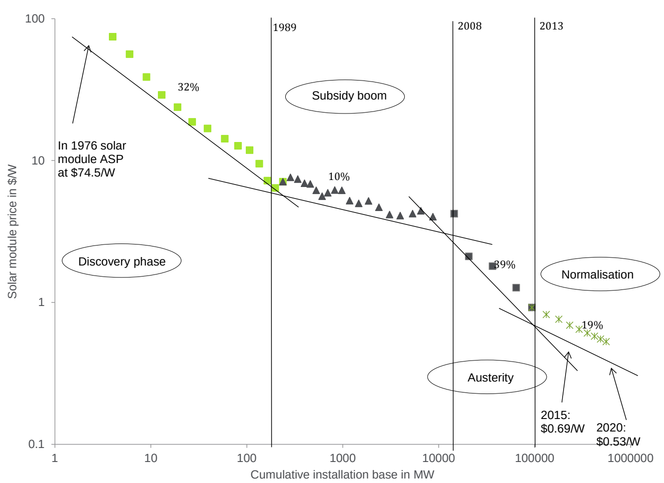
Hence the report highlighted the lack of certainty over returns on many investments at the upper end of the cost curves in the energy industry over the next five years, let alone their total lives, which could be anywhere up to 40 years. This effect has become even more prevalent even more quickly than we anticipated, with significant quantities of stranded assets across the whole breadth of energy industry, from coal mines, gas fields, to power generation facilities. Accordingly, understanding those rates of change and the risk of stranded assets (and whether assets will actually be built, thereby affecting capex spend, given the lack of certainty over returns) becomes ever more important. As before, we are not trying to say that LCOE is 'better' than a capex based approach, rather each has its own advantages, and an LCOE approach highlights certain aspects that could be missed in a capex only approach; examining LCOE in conjunction with capex-based approaches should therefore add to the debate.

Renewable Energy's 'Technology' Characteristics

Learning rates for renewables should continue making the technologies ever more competitive, and ultimately cheaper than conventional, as is the case in many markets already

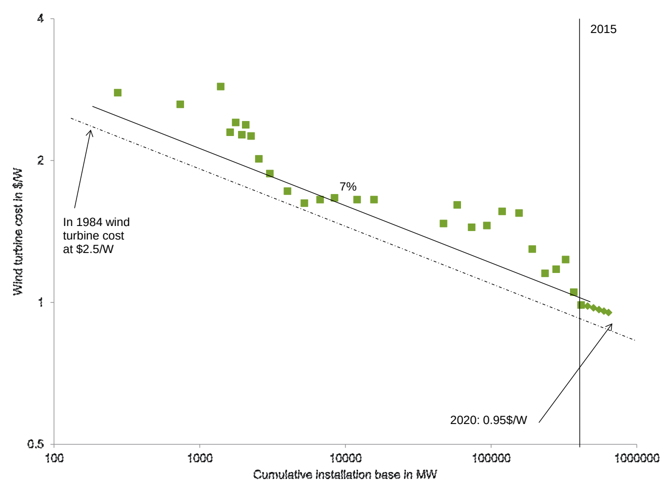
We expect installation costs for wind turbines and solar modules to continue to decline rapidly. Admittedly past declines in the solar PV space will be more difficult to replicate as there were many one-offs such as the manufacturing move to China and margin compression across the value chain. We estimate that going forward learning rates in solar PV modules will be up to 19% whilst onshore wind turbine learning rates are likely to hover around 7%. We find it useful to convert these learning rates (which express cost reductions for every doubling of installed capacity), into year on year reductions. For solar PV modules the year on year reduction would amount to 2% whilst for onshore wind this number is 1%.

Figure 39. Solar Learning Rate 19%



Source: BNEF, Citi Research

Figure 40. Wind Learning Rate 6.7%



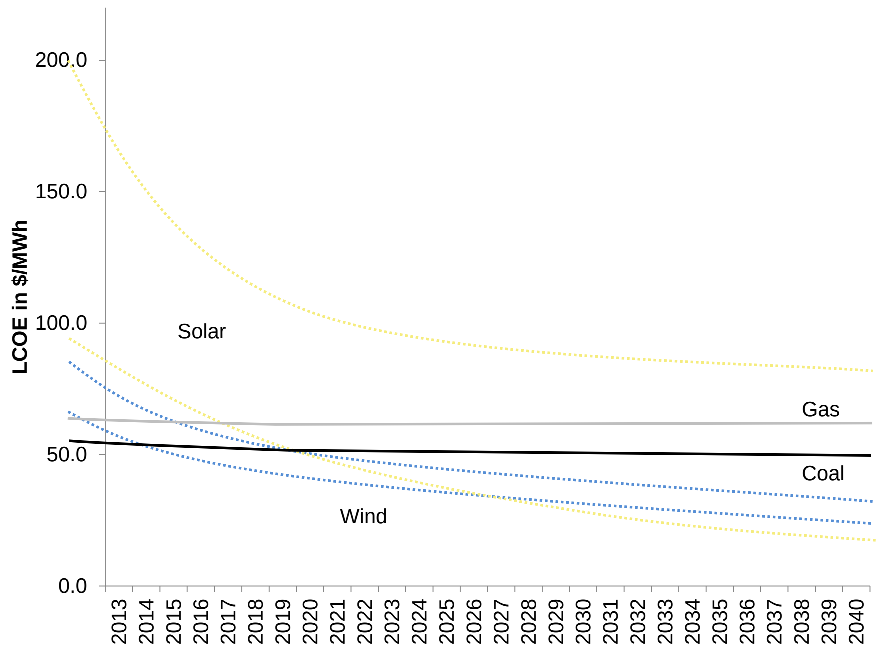
Source: BNEF, Citi Research

Why Renewable Energy Could be a Viable Solution

Renewable energy will become much more competitive in the future

In the initial years, the cost of procurement from carbon-light sources such as renewable energy is costly (solar at ~$90-180/MWh, wind at $60-80/MWh, versus coal at $60-70/MWh and gas at $50-100/MWh). Solar PV in particular is more expensive than conventional fuels in most parts of the world (with exceptions in regions with abundant sunshine such as Latin America and the Middle East). However, as component costs and financing of renewable projects decline, renewable energy becomes more competitive – for onshore wind, parity is reached earlier than for solar PV. Beyond that point there is a financial advantage in installing renewable energy and we should think of installing renewable energy as a benefit rather than a cost to society. Figure 41 shows our estimates of the global cost of power by various fuel-types.

Figure 41. Cost of Energy from Renewables Expected to Fall Drastically Over the Next Years



Source: Citi Research

This is one of the key benefits of examining total spend on an LCOE basis, as it demonstrates well the shifting relative economics of different generation technologies. Most important is this point that as renewables become 'cheaper' than conventional, there is effectively a net saving to using them.

The Disadvantages of an LCOE Approach

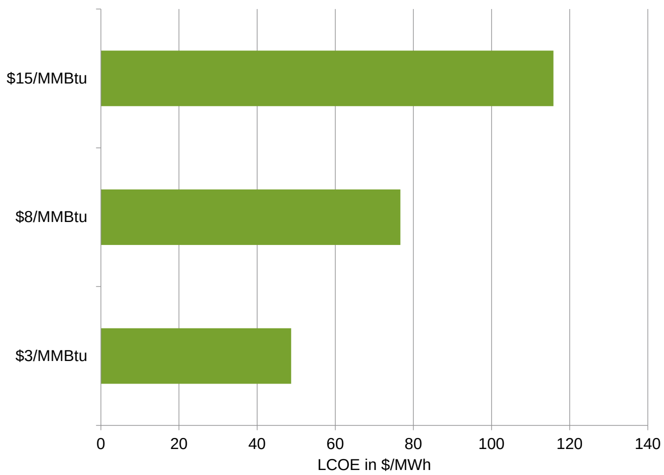
The disadvantages to using LCOE, or conversely the advantages of using a purely capex-focused approach are as follows:

- The main argument against the use of LCOE and total costs is that it requires significant assumptions on commodity prices, which are of course extremely difficult to forecast with any accuracy particularly over a 25 year time horizon. However, one could counter that those prices will have an equally large impact on the returns that the upstream capex will generate – by assuming that fuel costs are adequately captured by upstream capex therefore assumes that an adequate return will be earned on that investment, and therefore it could be argued makes just as large indirect assumptions on future commodity prices as an LCOE approach does. This highlights once again the work contained in the original Energy Darwinism report, that the pace of change in energy markets makes returns on investment highly uncertain for many forms of energy assets, particularly conventional.

- It can be argued that a purely capex-based approach *does* incorporate fuel costs, in that they are effectively captured in the upstream investment into coal mines, oil and gas fields etc., the fuel 'costs' essentially providing a return on the capital investment. However, once again this assumes that load factors, fuel costs and selling prices will be adequate, and hence once again assumes in many ways just as many assumptions as an LCOE approach does.

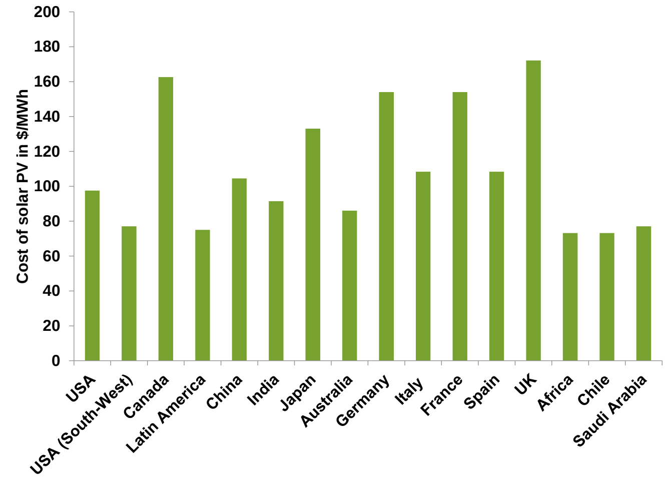
- The costs of both conventional and renewable energy vary significantly by region. The economics of gas-fired plant are most sensitive to gas prices, in which there is a large discrepancy between regions as shown in Figure 42. In the US the shale gas boom has drastically driven down gas prices and the oil price drop has now brought gas prices down to below $3/MMBtu. However, in other regions, gas prices are still higher due the lack of availability, such as Europe where gas trades at $7-8/MMBtu, and in Japan with gas prices up to $15/MMBtu. These price discrepancies across regions have a large impact on the economic viability of gas-fired plants vs renewables. The economics of renewable energy also vary significantly around the world. In particular the cost of solar PV electricity is very sensitive to insolation levels (sunshine hours), which varies drastically across regions as highlighted in Figure 43.

Figure 42. Gas Economics Heavily Depend on Gas Price



Source: Citi Research

Figure 43. Solar PV Cost of Electricity Generation Across Different Regions – Citi Projections for 2015



Source: Citi Research

Capex vs. LCOE Conclusions

So, both a purely capex-based approach and an LCOE approach have benefits and limitations. By choosing to use an LCOE approach we are not saying it is better – merely different, and it does highlight some of the benefits of following a low carbon path. In reality of course neither approach is perfect, and while there are arguments that there are 'less' assumptions in adopting a capex-based approach, this has been done very effectively by institutions such as the IEA, and to replicate it here might add limited additional value to the debate. What adopting an LCOE and holistic approach alongside the capex-based work does emphasize is the rapidly reducing costs of alternative energy, and in particular the ultimate savings via lower spend on commodities used in a lower carbon path.

Figure 44. The Advantages and Disadvantages of a Capex-Based Approach and LCOE

Advantages of capex/ disadvantages of LCOE	Advantages of LCOE/disadvantages of capex
Less apparent assumptions on fuel costs vs. LCOE	Total costs of generation vary widely by technology between upfront capex and fuel cost
Less regional variation in costs vs. LCOE	Does not penalize up front cost nature of renewables if discounting is used
Avoids transportation cost assumptions	Highlights effects of fuel savings via renewables
Intermittency of renewables and associated grid costs is not captured in LCOE (unless associated T&D etc. spend is adjusted)	Highlights relative speeds of changes in costs of differing generation technologies

Source: Citi Research

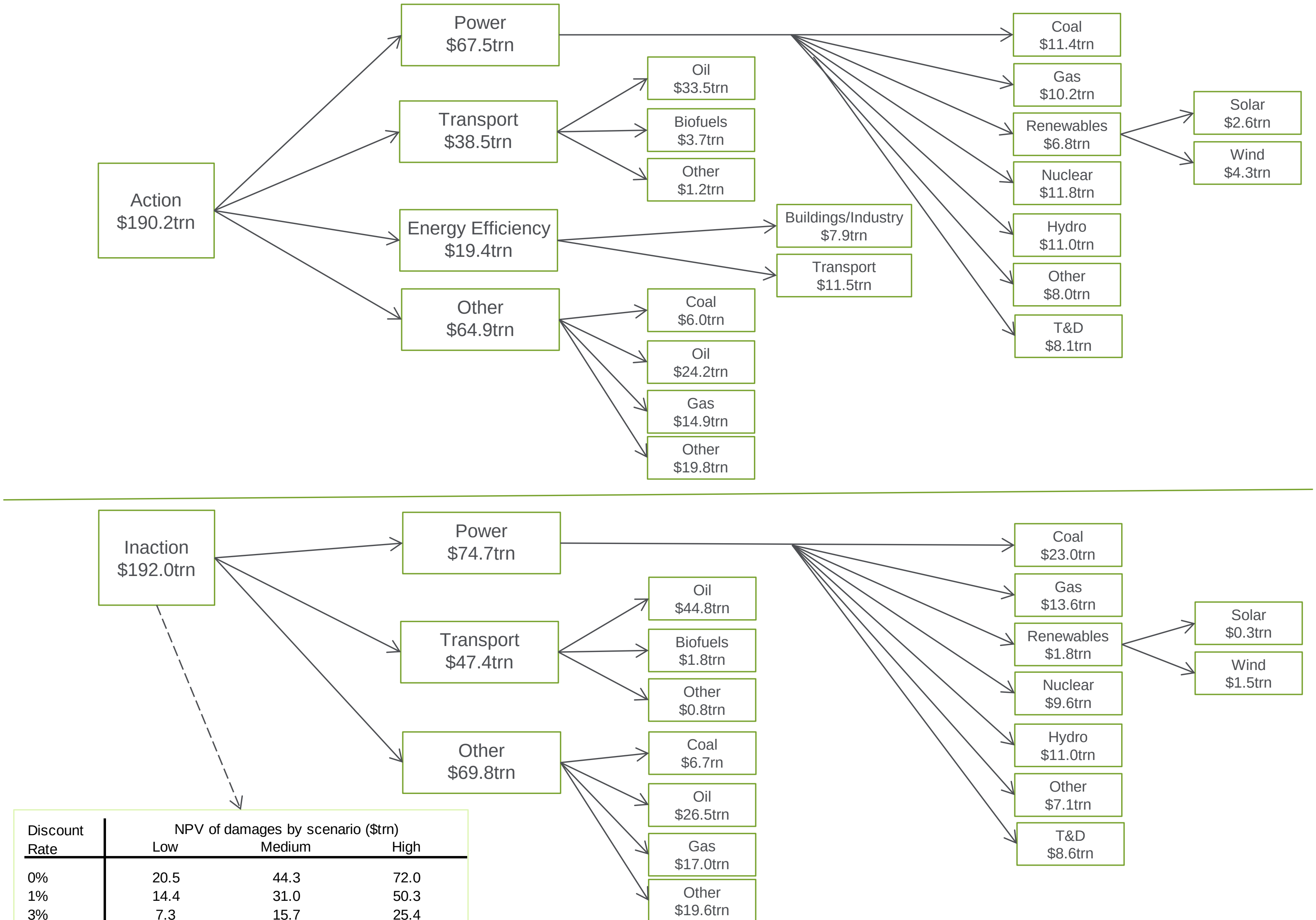
Assessing the Global Spend on Energy Over the Next Quarter Century

As discussed, while other methods assess the investment required in energy to follow a low carbon path, we have adopted a slightly different approach, looking at the potential total energy spend under differing energy mix assumptions. The holistic approach provides an additional perspective that can be used alongside a purely capex-focused approach, allowing us to examine its significance in different ways such as allowing us to assess the total amount spent on energy supply in a year relative to the size of the global economy, as well as gaining a perspective into the quantity of stranded assets potentially 'created' by following a low carbon path.

Applying the LCOE assumptions to our adapted global power model produces the total spend scenarios outlined in Figure 45. To be clear, this chart shows not just the capital investment required in power, but incorporates the cost of fuel used. For other areas of use it incorporates energy usage at current Citi commodity forecast prices and then held flat from 2018 onwards to 2040. In terms of assumptions we have not made any assumptions on long term commodity prices beyond 2018, but simply assumed that these prices remain flat over the life of the analysis. Clearly changes in commodity prices (discussed in a later section) would have a material impact on relative costs and savings, though we would note that the low nature of some commodities such as oil reduces investment therein, as well as potential savings from not using that fuel (i.e. following a low carbon path).

The detailed analysis of the costs of the impact of climate change, and increased investment in both the power market and energy efficiency is provided in dedicated chapters later in this report. However, at this stage we provide a summary of those holistic costs of capex and fuel spend to the global economy over the next quarter century, as shown in Figure 45.

Figure 45. Estimated Spend on Energy Globally, 2015-40 Under Citi's 'Action' and 'Inaction' Scenarios, vs. Potential 'Costs' of Climate Change

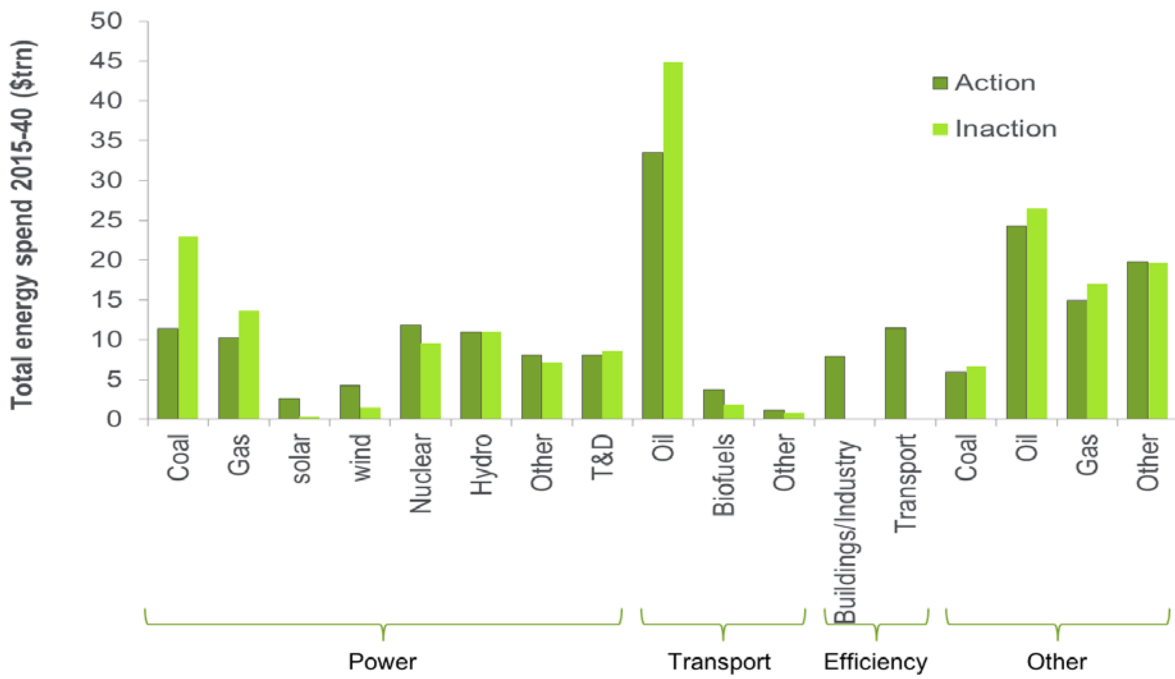


Discount Rate	NPV of damages by scenario ($trn) Low	Medium	High
0%	20.5	44.3	72.0
1%	14.4	31.0	50.3
3%	7.3	15.7	25.4
5%	3.9	8.3	13.4
7%	2.2	4.7	7.4

Note: Pricing assumptions from 2018 onwards for illustration purpose only: Coal at $74/mt, Gas at $6.95/mmbtu and Oil at $80.80/bbl

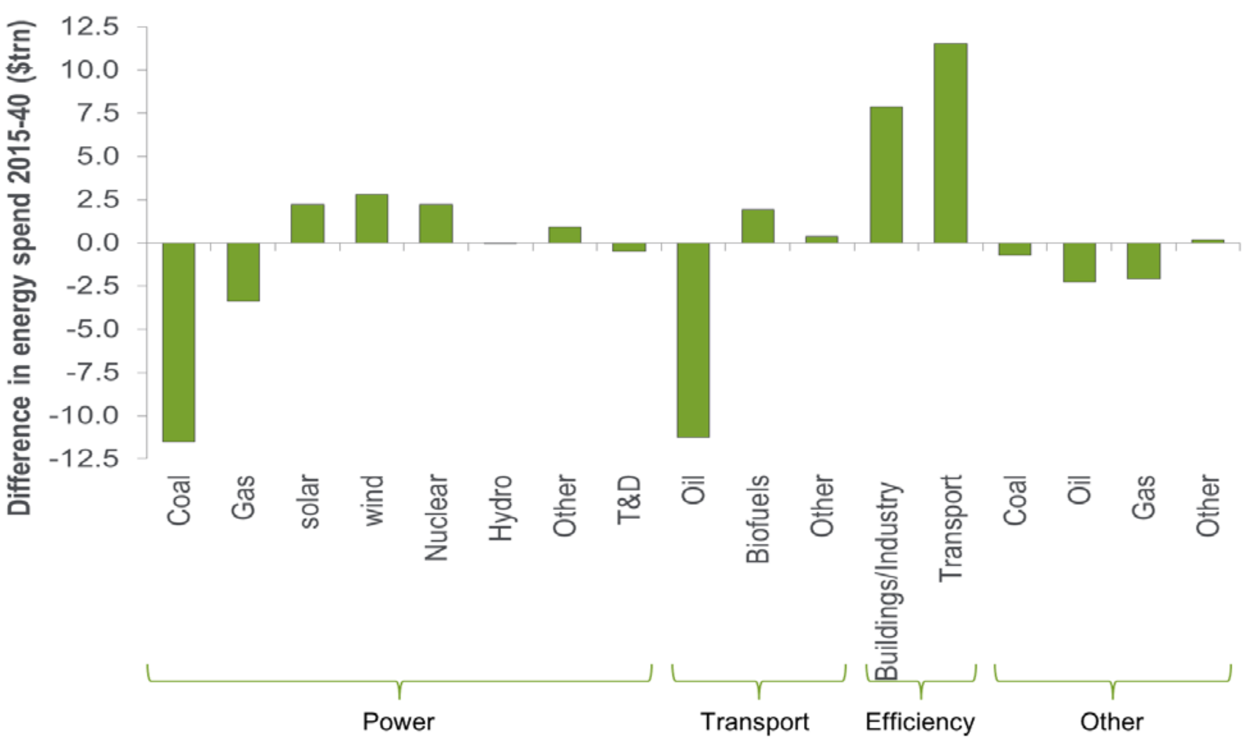
Source: Citi Research

Figure 46. Changes in Total Energy Spend Between our 'Action' and 'Inaction' Scenarios.



Source: Citi Research

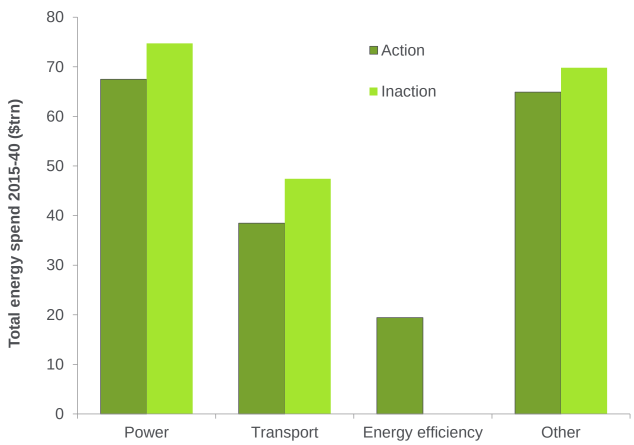
Figure 47. Difference in Total Investment Between our 'Action' and 'Inaction' Scenarios, 2015-2040.



Source: Citi Research

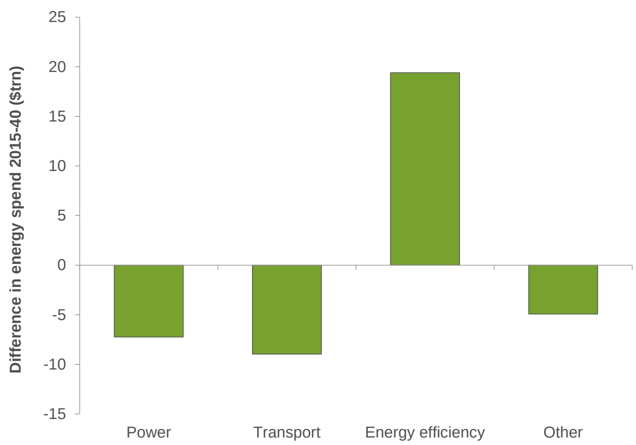
Figure 45 shows the total spend and split therein of energy spending over the next 25 years under both our 'Action' and 'Inaction' scenarios. While electricity (the main focus of this report examined in more detail in a later section) is calculated on an LCOE basis, other areas such as transport are calculated using the expected volumes used, multiplied by current forecast prices, with prices held constant beyond 2018 (i.e. no assumptions are made regarding changes to prices). Clearly this latter point is important – if commodity prices such as oil had not plummeted in recent months, the total spend figures would be considerably higher.

Figure 48. Energy Spend in 'Action' and 'Inaction' Scenarios by Segment, 2015-40



Source: Citi Research

Figure 49. Change in Energy Spend in 'Action' and 'Inaction' Scenarios by Segment, 2015-40



Source: Citi Research

The difference in spending between the 'Inaction' and 'Action' scenario is marginal

While not perfect, this approach is designed to capture how much we will 'spend' on energy over the next quarter century. The key point to take is that the difference in total spend is marginal between the two scenarios, mainly because although we spend significantly more on renewables and energy efficiency in the 'Action' scenario, this is offset by reduced spend on fossil fuels (as renewables don't use 'fuel', and energy efficiency is effectively negative fuel use). However, if we go down the route of 'Inaction' and do not invest into a low carbon economy, we could potentially face some negative impacts such as changes to rainfall patterns, a reduction in crop production, an increase in sea level rise etc., the estimated costs of which are highlighted in the box on Figure 45. Whilst these could ultimately affect the livelihoods of many people, they will also have a negative effect on global GDP. This is addressed in more detail in other chapters.

This approach also makes it easier to compare the costs of energy to global GDP in terms of energy acting as a brake or accelerator for global growth in a way that analyzing purely capex perhaps doesn't. It also gives a sense of the value of the assets which remain 'unused', i.e. becoming stranded under a low carbon scenario. Admittedly this approach would vary dramatically depending on pricing assumptions, but as we discussed in a later chapter, it highlights the decreasing proportion of total energy costs which are in fact fuel.

Drivers of Change (1): The Power Market Transformation

Highlights

- The power market is the single largest carbon emitter in the energy market and currently emits 12.6GT CO_2e in 2015. This number is projected to double by 2040 in the absence of investments into abatement measures such as renewable energy (mainly solar PV and onshore wind) and energy efficiency to reduce electricity consumption.

- Coal is the single largest carbon emitter in the power market and makes up 41% of the fuel mix given its low cost, yet emits we estimate 73% of the total emissions from power generation.

- In this chapter we examine in detail our Citi 'Action' and 'Inaction' scenarios with a particular focus on the power sector as the largest single emitter. In particular we focus on where our scenarios differ from others such as those from the IEA; in summary we assume faster cost reductions and a greater penetration of renewables. While most examinations of cost focus purely on upfront capex, we have chosen to adopt a different approach, namely 'LCOE', which captures both the upfront investment costs and operating costs (including fuel) thereafter.

- In summary we find that the incremental cost of following a low carbon route in the power sector (our so-called Citi 'Action' scenario) is only around $1.1 trillion out to 2040. While costs are more expensive in early years, as renewable technologies become cheaper in later years due to their impressive learning rates, we effectively save money via the lower fuel usage in conventional plants, as well as reduced overall consumption via investment in energy efficiency.

- As a result, carbon emissions in the order of 200GT CO_2e can be avoided between 2015 and 2040. A third of the avoided carbon can be attributed to energy efficiency investments and the other two thirds can be attributed to renewable energy investments.

- We examine the implications of these incremental costs for a potential price of carbon, how it might vary around the world, and then incorporate a cost of carbon into the original 'Energy Darwinism' integrated global energy cost curves to examine the implications for stranded assets. Unsurprisingly, coal is the biggest loser, while the key beneficiaries are renewables given their limited lifetime emissions.

- We also highlight the potential that energy storage offers, in terms of offsetting the intermittency of renewables, as well as its wide reaching implications for energy markets overall.

Citi's Trajectory into a Carbon-Light Electricity Mix

In order to make a cost and impact assessment, we look at the Citi 'Action' and 'Inaction' scenarios and assess the investment requirements and the impact on carbon emissions under both scenarios:

Citi 'Action' scenario: This scenario reflects a transition to a carbon-light electricity mix and investments in (1) renewable energy and (2) energy efficiency to mitigate CO_2 emissions. In this scenario we assume an electricity generation CAGR of 1.6% between 2015 and 2040 – a lower rate than our 'Inaction' scenario due to energy efficiency investments. Further our Citi 'Action' scenario assumes renewable energy penetration increases to 34% by 2040 from 6% in 2012.

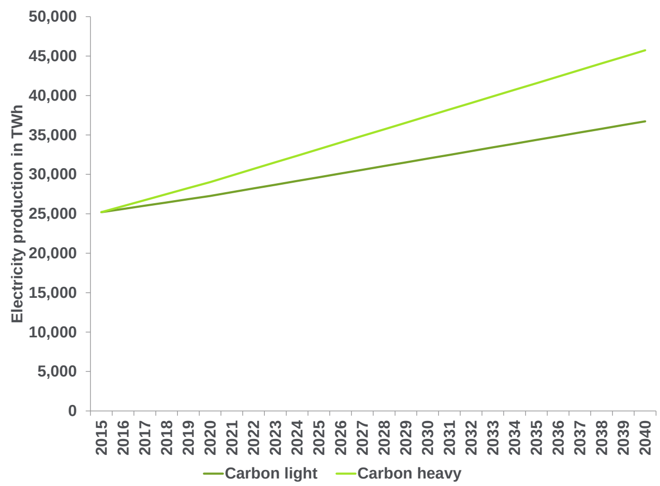
Citi 'Inaction' scenario: This scenario reflects no change in our current carbon-heavy electricity mix. In this scenario renewables investment will pick up but will only stay at 6% penetration by 2040. Fossil fuels will make up two thirds of our electricity mix with coal continuing to take the largest market share with 40%. Further this scenario assumes a higher electricity generation CAGR of 2.4% between 2015 and 2040 due to zero investments into energy efficiency.

Power consumption will grow at a lower rate in our 'action' scenario; fossil fuels would decline from 65% to 28% of the power market

In our 'Action' scenario where investments are triggered, we estimate power consumption to grow at a slower rate than in our inaction scenario due to investments into energy efficiency. In 2040 we estimate this gap to widen to 20% between both of our scenarios (Figure 50).

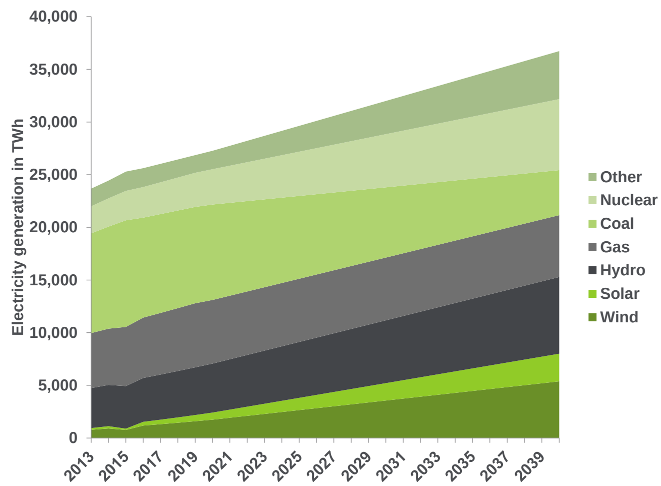
For the electricity mix we have assumed that in our status quo scenario the electricity mix stays constant over time weighted towards fossil fuels – coal 40%, gas 22% and renewables 6%. In our Citi 'Action' scenario we have assumed that the fossil fuel share declines from currently over 64% to 28% whilst solar PV and onshore wind energy could make up to 22% of the electricity mix in our Citi 'Action' scenario (Figure 51).

Figure 50. Annual Electricity Production for Both Citi Scenarios



Source: Citi Research

Figure 51. Carbon-Light Scenario Sees Fossil Fuel Share to Decline from 64% in 2015 to 28% in 2040



Source: Citi Research

Where Are We Different From the IEA?

Solar PV would increase at 53GW per annum from 2013-2020

The key difference between our forecasts and the IEA's is the assumed penetration of renewable energy in the electricity mix. In our Citi 'Action' scenario we have assumed a higher rate of penetration for solar PV and onshore wind installations (Figure 53 and Figure 54). In particular, our forecasts for solar PV deviate significantly from the IEA's.

Figure 52. Fuel Mix for Electricity Generation by 2020

2020	Citi Action	Citi Inaction	IEA 450	IEA CPS
Fossil	58.3%	67.4%	60.3%	64.1%
Renewables	12.4%	5.8%	10.3%	9.0%
Nuclear	12.3%	10.7%	12.3%	11.3%
Hydro	17.0%	16.0%	17.0%	15.6%
Total	100%	100%	100%	100%

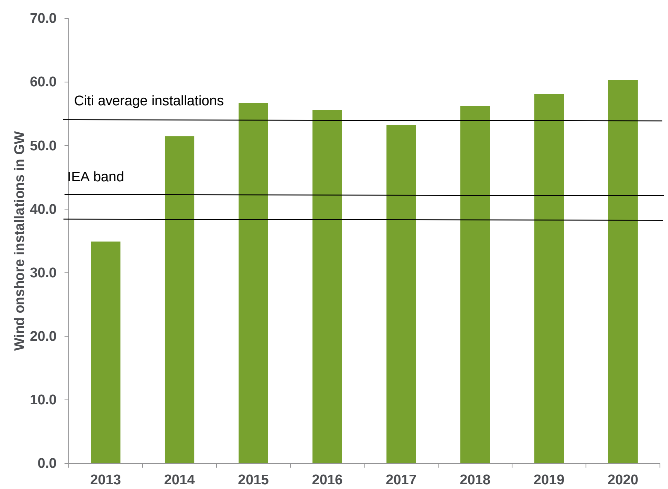
Source: Citi Research

Our granular country by country solar PV forecasts show an average installation rate of 53GW per annum 2013-2020. This compares to 33-34GW installations by the IEA (lower bound New Policy scenario, upper bound 450 scenario), as seen in Figure 53. These differentials are also clear in our wind assumptions (Figure 54).

Figure 53. Citi Solar PV Installations

Source: IEA (2014), Citi Research

Figure 54. Citi Onshore Wind Installations



Source: IEA (2014) Citi Research

Our bottom-up assumptions for both wind and solar by country are shown in Figure 55 and Figure 56.

Figure 55. Citi Solar PV Forecasts

Annual Demand (MW)	2007A	2008A	2009A	2010A	2011A	2012A	2013A	2014A	2015E	2016E	2017E	2018E	2019E	2020E
Europe	2,362	4,835	6,763	12,014	21,478	15,236	10,572	6,985	7,836	7,066	8,240	8,762	9,204	9,669
Italy	70	338	719	2,321	9,446	3,564	1,364	395	533	720	756	794	833	875
Germany	1,400	1,600	4,500	7,392	7,485	7,600	3,304	1,901	1616	1777	1866	1960	2058	2160
Spain	600	2,500	100	275	372	275	143	22	25	29	33	38	44	51
France	50	100	100	707	1,671	1,022	649	926	1019	1120	1233	1294	1359	1427
UK	0	0	0	115	784	725	1,082	2,273	2955	1477	2216	2327	2443	2565
ROE	242	297	1,344	1,204	1,720	2,050	4,030	1,468	1688	1941	2136	2349	2467	2590
North America	200	350	400	1,129	1,961	3,568	5,056	6,908	9,177	12,212	6,840	7,182	7,542	7,919
USA	200	350	350	984	1,712	3,300	4,621	6,312	8,521	11,504	6,097	6,402	6,722	7,058
Canada	0	0	50	145	249	268	435	596	656	708	743	781	820	861
South America	3	3	7	5	11	95	103	614	1,297	1,752	2,103	2,314	2,545	2,799
Chile	0	0	0	0	0	2	13	483	773	966	531	584	643	707
Rest of Latam	3	3	7	5	11	93	90	131	524	786	1572	1729	1902	2092
Asia	390	630	840	1,953	5,272	8,832	22,117	25,357	29,067	30,635	30,678	32,524	34,119	35,564
Japan	300	300	500	900	1,155	2,000	7,092	10,253	9,000	8,000	6,000	6,060	6,121	6,182
China	40	30	200	450	3,240	5,000	12,920	13,000	16,000	17,600	18,480	19,404	20,374	21,393
Korea	50	300	100	148	157	252	361	480	490	499	509	520	530	541
India	0	0	20	95	300	980	968	815	2,000	2,800	3,780	4,536	4,990	5,239
Other Asia	0	0	20	360	420	600	776	809	1,578	1,735	1,909	2,004	2,104	2,210
Asia Pac	20	20	100	387	774	1115	861	921	939	958	977	997	1017	1037
Australia	20	20	100	387	774	1,115	861	921	939	958	977	997	1017	1037
South Africa	0	0	0	0	2	7	177	901	1,126	1,408	1,760	2,112	2,534	3,041
ROW	100	100	150	1,942	2,606	2,200	1,392	3,315	4,973	6,216	10,567	11,095	11,650	12,232
Total	3,075	5,938	8,260	17,430	32,104	31,053	40,278	45,001	54,415	60,246	61,165	64,985	68,610	72,261

Source: Citi Research

Figure 56. Citi Onshore Wind Forecasts

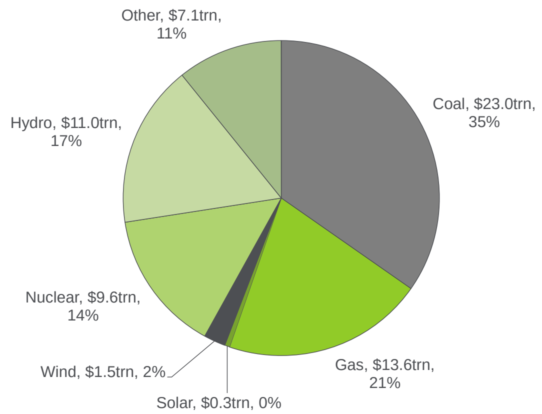
Annual installations (MW)	2007 A	2008 A	2009 A	2010 A	2011 A	2012 A	2013 A	2014 A	2015 F	2016 F	2017 F	2018 F	2019 F	2020 F
Asia	5,226	8,391	15,451	21,468	20,963	15,645	18,212	26,006	31,414	29,215	30,297	31,919	32,425	33,000
China	3,304	6,110	13,785	18,928	17,631	12,960	16,088	23,196	28,000	25,000	25,000	26,000	26,000	26,000
India	1,575	1,810	1,271	2,139	3,019	2,337	1,729	2,315	2,778	3,334	3,667	4,034	4,235	4,447
Japan	229	342	205	249	202	78	47	130	260	494	1,235	1,482	1,778	2,134
Rest of Asia	118	129	190	152	111	270	348	365	376	387	395	403	411	419
Europe	8,662	8,601	10,730	10,176	10,396	12,774	11,660	12,857	10,184	10,516	11,050	11,581	12,120	12,737
Germany	1,667	1,656	1,874	1,414	1,880	2,199	2,980	5,279	2,500	2,500	2,500	2,500	2,500	2,500
Spain	3,522	1,544	2,471	1,463	1,051	1,110	175	28	50	50	50	50	50	50
Denmark	3	38	302	284	207	206	610	105	100	100	100	100	100	100
Italy	603	1,010	1,113	948	1,081	1,240	434	108	111	115	116	117	118	119
France	888	950	1,170	1,396	837	816	631	1,042	1,250	1,438	1,582	1,740	1,827	1,918
UK	427	568	1,271	1,003	1,308	2,093	1,882	1,736	1,500	1,620	1,750	1,890	2,041	2,204
Portugal	434	712	673	171	673	150	195	184	190	195	197	199	201	203
Netherlands	210	478	- 10	54	3	119	302	141	145	150	151	153	154	156
Sweden	217	260	512	603	736	847	724	1,050	890	600	550	490	460	450
Poland	123	268	181	455	436	880	894	444	488	537	591	650	715	787
Turkey	-	311	343	528	477	506	647	804	965	1,158	1,389	1,598	1,837	2,113
Rest of Europe	568	806	830	1,857	1,707	2,608	2,186	1,936	1,994	2,054	2,074	2,095	2,116	2,137
North America	5,630	8,767	11,083	6,218	7,938	14,985	3,063	7,359	9,851	10,392	6,559	7,087	7,629	8,220
US	5,244	8,244	10,018	5,212	6,631	13,078	1,084	4,854	7,000	8,000	4,000	4,400	4,840	5,324
Canada	386	523	950	689	1,257	939	1,599	1,871	2,058	1,441	1,513	1,588	1,636	1,685
Mexico	-	-	115	317	50	968	380	634	793	951	1,046	1,098	1,153	1,211
Latam	30	121	538	372	804	1,249	1,234	3,750	3,691	3,889	4,102	4,330	4,575	4,838
Brazil	10	94	265	321	504	1,077	953	2,472	2,596	2,725	2,862	3,005	3,155	3,313
Chile	18	-	148	4	-	33	130	506	300	345	397	456	525	603
Rest of Latam	2	27	125	47	300	139	151	772	795	819	844	869	895	922
Pacific Region	158	485	578	295	345	358	655	567	600	600	200	200	200	200
Australia	7	482	406	278	236	358	655	567	600	600	200	200	200	200
Rest	151	3	172	17	109	-	-	-	-	-	-	-	-	-
Africa and Middle East	160	98	230	199	5	95	90	934	926	988	1,055	1,130	1,212	1,302
Ethopia	-	-	-	-	-	81	90	-	-	-	-	-	-	-
Egypt	80	55	65	120	-	-	-	-	-	-	-	-	-	-
Morocco	60	10	119	33	5	-	-	300	300	300	300	300	300	300
South Africa	-	-	-	-	-	-	-	560	616	678	745	820	902	992
Rest	20	33	46	46	-	14	-	74	10	10	10	10	10	10
Total	19,866	26,463	38,610	38,728	40,451	45,106	34,914	51,473	56,665	55,600	53,263	56,246	58,160	60,298

Source: Citi Research

$1.1 Trillion: The Cost of Overhauling the Power Market

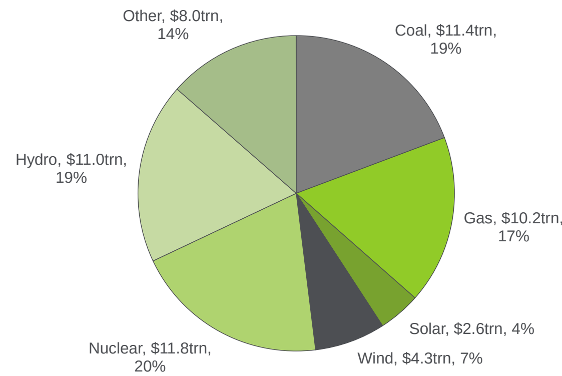
Figure 57 and Figure 58 show the split of total investment in the power market under the two different Citi scenarios. As the charts show, the difference in the total bill between 2015 and 2040 is $6.9 trillion, with 'Action' being less costly, though of course this ignores the increased investment in energy efficiency which more than offsets this saving.

Figure 57. Total Spend on Electricity Using an LCOE Approach in Citi's 'Inaction' Scenario. (Total spend = $66.1trn)



Source: Citi Research

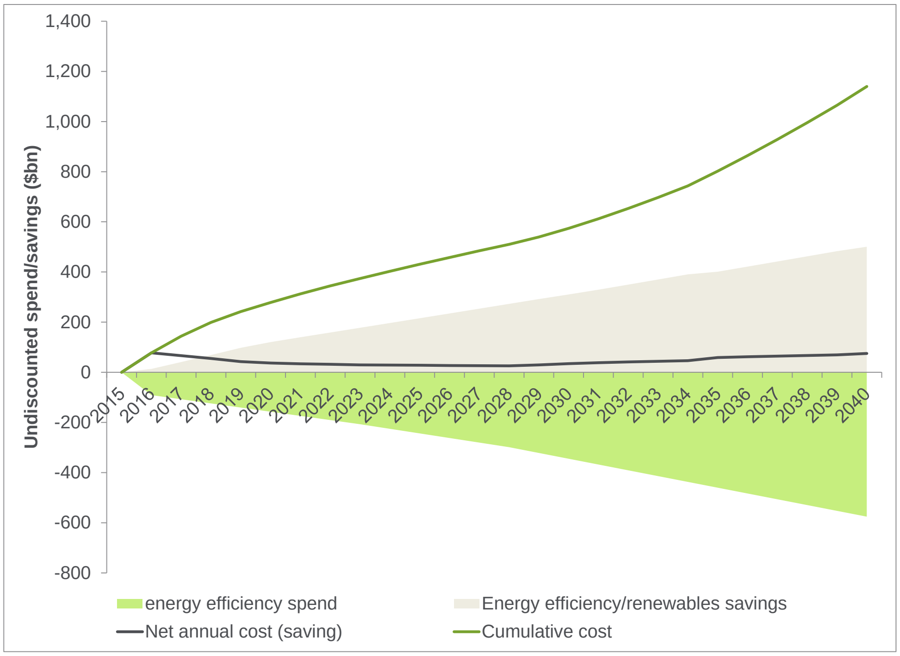
Figure 58. Total Spend on Electricity Using an LCOE Approach in Citi's 'Action' Scenario. (Total spend = $59.4trn)



Source: Citi Research

Converting these differentials to a timeline showing incremental investment vs. savings on power costs produces the results shown in Figure 59.

Figure 59. The Net and Cumulative Incremental Costs of Following the Citi 'Action' Scenario



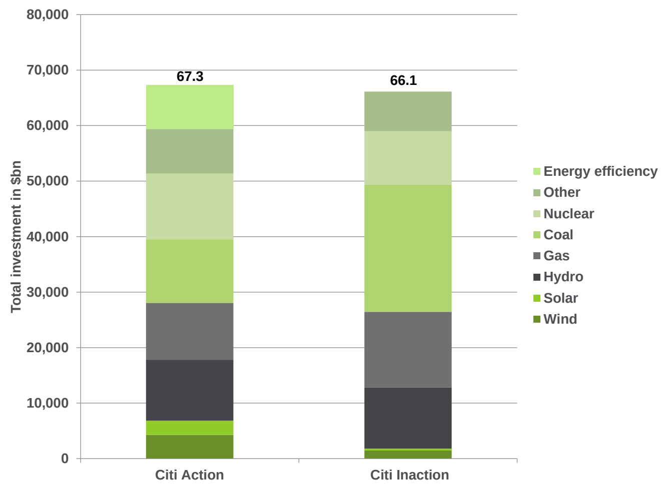
Source: IEA (2014), Citi Research

We estimate that by 2030 the cost of power production from renewables will have come down far enough to be fully cost competitive. However, this benefit is then offset by investments needed for energy efficiency on both the demand-side and the industry-related side.

Cumulative incremental electricity investment between both scenarios would amount to $1.1 trillion

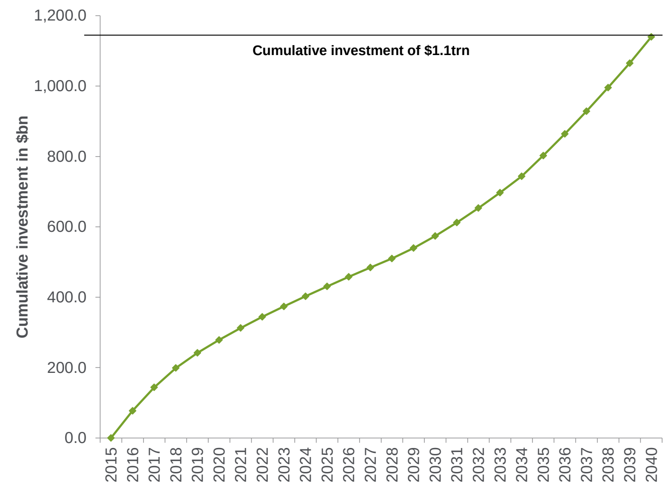
Overall, in the period 2015-2040 we estimate that cumulative incremental investments will amount to $1.1 trillion, as highlighted in Figure 59, Figure 60, and Figure 61.

Figure 60. Total Investment in Both Citi Scenarios 2015-40 (Including Efficiency, but Excluding T&D Spend)



Source: Citi Research

Figure 61. Incremental Difference in Investments Annually Between Both Scenarios



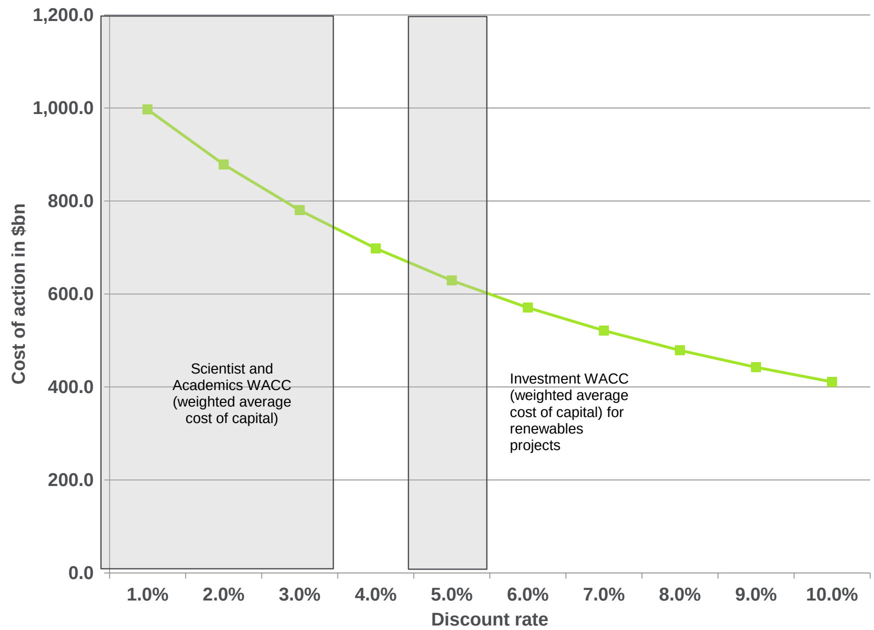
Source: Citi Research

However, this amount could be a smaller sum if one discounts those costs that arise in the future. The question then becomes what is the right discount rate to use when considering investments into a carbon-light power market. From an investment point of view one would consider the cost of capital of renewable projects. Ultimately project owners and bank providers bear the financial risk when investing into these infrastructure projects. Further, the equity on projects bears the majority of financial risk for those projects. Currently the cost of equity for renewables projects is around 5-7% depending on what type of asset and how stable and trustworthy the regulatory regime is deemed. However as our investment costs are denominated in real terms, the corresponding cost of equity could drop by 1-2% to bring the real project cost of equity to around 4-5%.

However, contrary to the argument that investments into a carbon-light future should be discounted from a financial viewpoint, climate change scientists have argued that discounting should reflect an inter-generational trade off, as discussed earlier. Fundamentally, the idea of discounting is being used in finance because monetary value can be enhanced from one period to another via say a bank savings account, and therefore a higher monetary value is assigned to the present. When considering climate change, some scientists argue that society should not use any form of discounting as it implicitly assigns a higher value to present generations vs. future generations.

The difference between a low discount rate and a discount rate that reflects the equity risk of renewable projects can bring down costs from $1.1 trillion to $0.4 trillion in net present value (NPV) terms. However we also note that a consistent discounting rate needs to be used when contrasting investments with avoided liabilities.

Figure 62. Cost of Action: How Much Does It Cost Society To Transform Our Current Electricity Market in Net Present Value (NPV) Terms



Source: Citi Research

Impact of Power Transformation on CO_2

For a 50% chance of meeting temperature increase of 2°C, cumulative GHG emissions need to be capped at 2,000GT CO_2e

In this section we examine our scenarios in emissions terms. Malte Meinshausen has predicted for an illustrative 50% chance to not exceed long term temperature rises beyond 2 degrees Celsius; the allowable greenhouse gas emissions budget is 2,000GT CO_2e between 2000 and 2049.

Meinshausen, who makes a distinction between greenhouse gases (Kyoto gases below) and carbon dioxide (CO_2), has attached the following probabilities to exceeding 2 degree Celsius in long term temperature rises for different greenhouse gases and carbon dioxide emission levels in Figure 63.

Figure 63. Meinshausen Greenhouse Gas Budget

		Probability of exceeding 2 degrees Celcius	
Indicator	**Emissions**	**Range**	**Illustrative default case**
Cumulative total CO2 emissions 2000-49	886Gt CO2	8-37%	20%
	1,000Gt CO2	10-42%	25%
	1,158Gt CO2	16-51%	33%
	1,437Gt CO2	29-70%	50%
Cumulative Kyoto-gas emissions 2000-49	1,356Gt CO2e	8-37%	20%
	1,500Gt CO2e	10-43%	26%
	1,678Gt CO2e	16-51%	33%
	2,000Gt CO2e	29-70%	50%

Source: Meinshausen et al (2009)

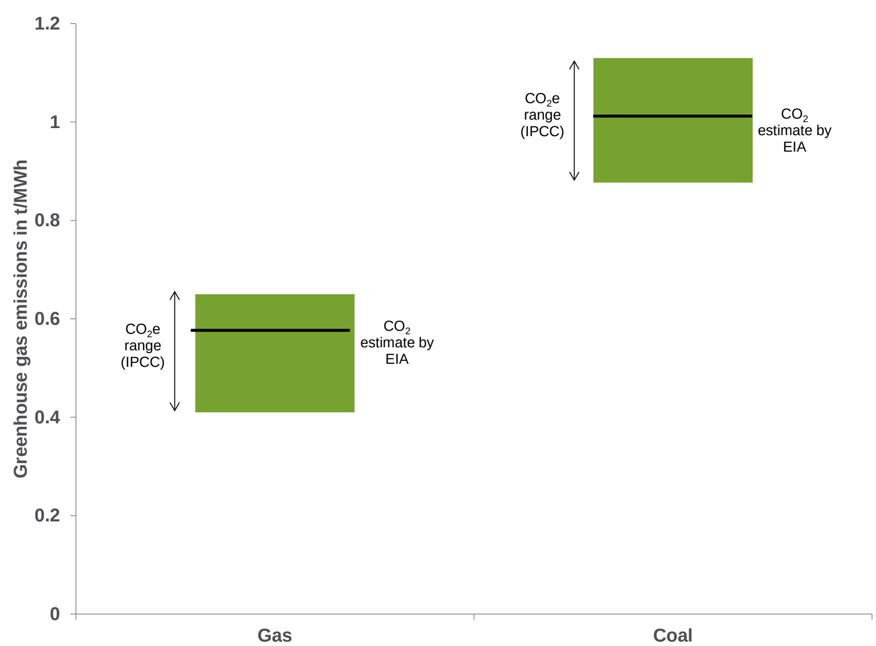
Difference between CO_2 and CO_2 Equivalent

One important distinction in the emissions debate is the difference between CO_2 emissions and CO_2 equivalent (CO_2e) emissions. CO_2e emissions measure greenhouse gases – this captures both CO_2 emissions plus other gases such as methane, F-gases and N_2O adjusted for their global warming potential relative to CO_2.

For the power market however, greenhouse gas emissions in CO_2e and CO_2 emissions are to a large extent aligned. The vast majority of emissions when generating electricity from fossil fuels are in the form of carbon dioxide, therefore there is little deviation between both CO_2 and CO_2e emissions in the power market. However, this depends on what is being measured. The IPCC (Figure 64) calculates the lifecycle GHG emissions (from cradle to source) of power generation. This includes not only the CO_2 emissions from the combustion of fossil fuels in power plants, but also methane and other greenhouse gas emissions from the extraction of fossil fuels, extraction of materials used for solar and wind power generation and transportation. The EIA data calculates only the CO_2 emissions from power generation and does not include other greenhouse gas emissions.

In the context of linking temperature rises to emissions, quoting the budget in CO_2e terms is a more accurate measure as it captures other important greenhouse gases on top of carbon dioxide which are responsible for global warming. Similarly the IEA quotes their 450 scenario in greenhouse gas terms, where the 450ppm refers to greenhouse gas concentration (CO_2e). Therefore, for this study we use CO_2e (IPCC figures) and compare those to the greenhouse gas budget described by Meinshausen which includes all cumulative Kyoto-Gas emissions.

Figure 64. Greenhouse Gas vs. Carbon Dioxide Emissions per Unit of Electricity Generation

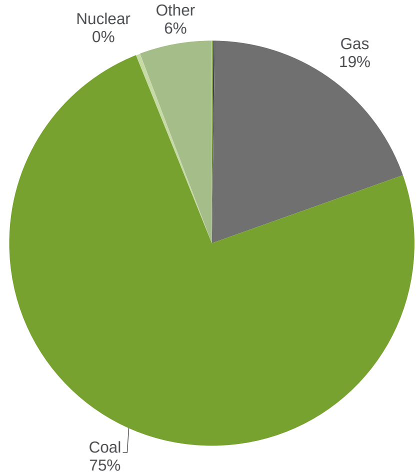


Source: IPCC (2014) and EIA

In 2015, coal and gas fired generation will emit 9.2 and 2.6 GT CO_2e respectively

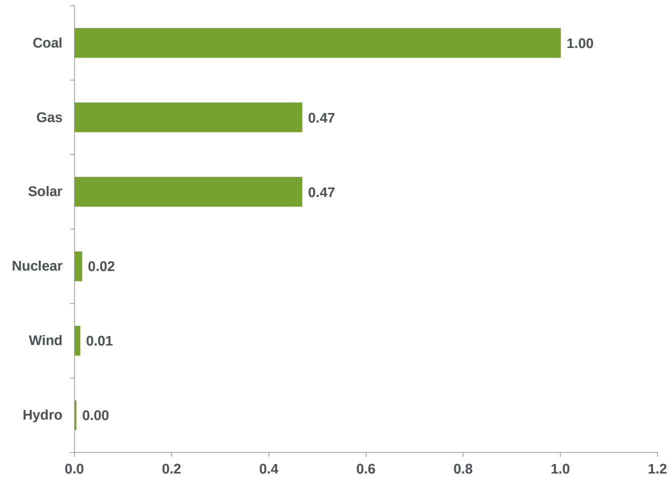
Currently, coal- and gas-fired electricity generation are the largest greenhouse gas emitters (CO_2e) in the power market (Figure 65), estimated at 9.2GT CO_2e and 2.6GT CO_2e, respectively. Future investments into energy efficiency will help reduce electricity consumption as a whole whilst substitution from coal-fired to gas-fired to renewable energy generation will reduce emission intensity. Both measures should lead to reduced greenhouse gas emissions of 9.3GT CO_2e by 2040, a 60% reduction compared to a business as usual scenario.

Figure 65. Total Greenhouse Gas Emissions in 2015 in Power Market – Citi Estimates



Note: 'Other' is mainly emissions from electricity generated from oil
Source: Citi Research

Figure 66. Greenhouse Gas Lifecycle Emissions in t CO_2e per MWh



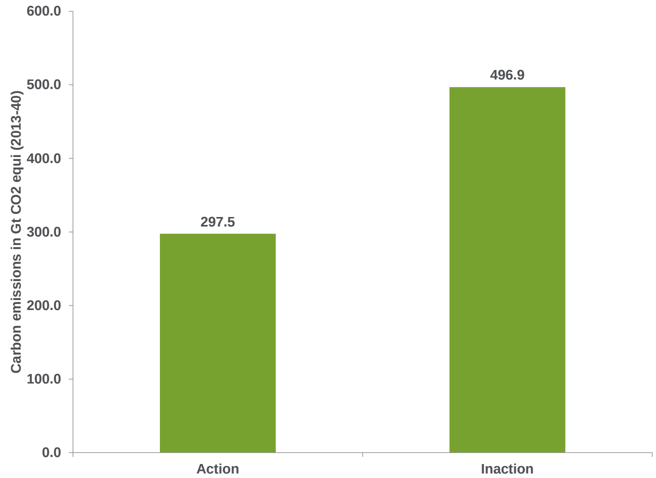
Source: Citi Research

There is a difference of over 200GT of CO_2e of cumulative emissions emitted between our action and inaction scenario

Implications of Citi Scenarios

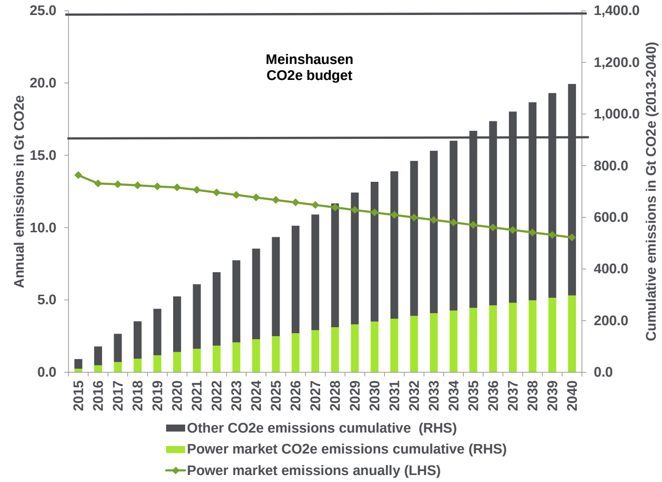
Our Citi 'Inaction' scenario implies cumulative CO_2e emissions of 500GT CO_2e between 2013 and 2040. In contrast our Citi 'Action' scenario, which assumes investments into renewables and energy efficiency, implies that this cumulative number reduces to 300GT CO_2e (Figure 67). In this scenario emissions are likely to stay flat between now until 2020 until the benefits of investments come through in the emissions data (Figure 68).

Figure 67. There is a CO_2e Discrepancy Between our Status Quo and Transformation Scenario



Source: Citi Research

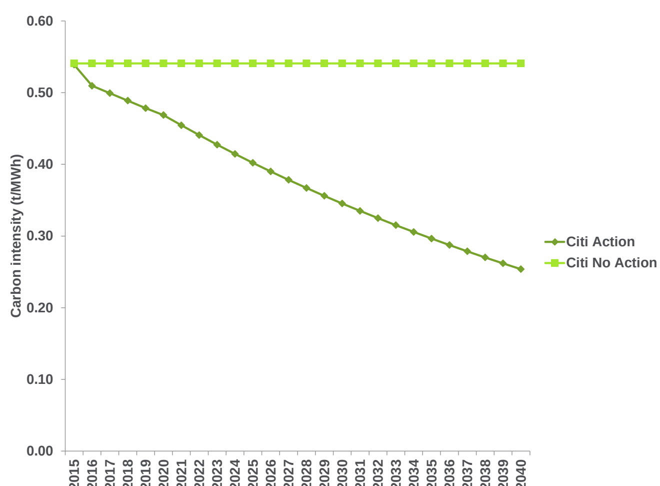
Figure 68. If Greenhouse Gas Emissions Were to Grow In Line with power Market Emissions (Citi 'Action' scenario)



Source: Citi Research

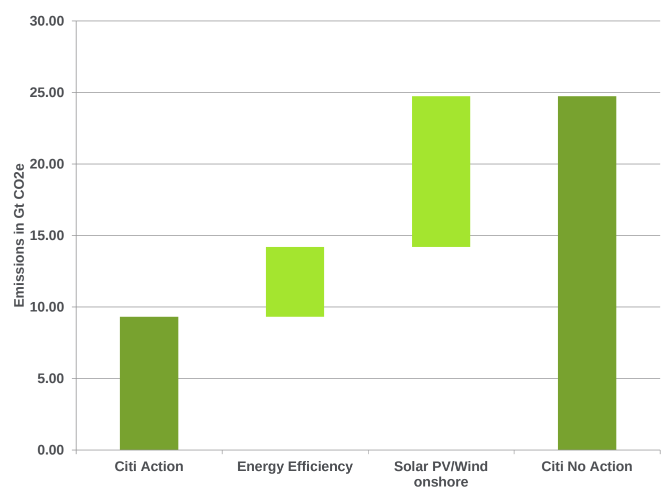
However, we highlight that the power market is not the only area where decisive action needs to be taken in order to limit climate change. For illustration, we show our cumulative emissions estimates in the power market under our 'Action' scenario in Figure 68, and assume that emissions from outside the power market such as land use, the transport market, industry etc. stay in similar proportions to what these areas emit today. The results are less encouraging, as they highlight that even tackling emissions in the power market as the single largest emitter, we still need to take decisive action in other carbon-heavy activities such as the transport market, (which we discuss in the next section), if we are not to blow through the 'carbon budget'. However, we would note that the simplistic approach to 'non-power emissions shown in Figure 68 potentially overstates their scale significantly.

Figure 69. Carbon Intensity Drops in Our Citi 'Action' Scenario



Source: Citi Research

Figure 70. Emissions in the Year 2040 – A Comparison Between Both Scenarios



Source: Meinshausen et al. (2009), Citi Research

Carbon intensity of electricity mix falls in our Citi 'Action' Scenario

In comparison with our Citi 'Inaction' scenario the carbon intensity of the electricity mix drops in our Citi 'Action' scenario from 0.54t (CO_2e)/MWh to 0.25t (CO_2e)/MWh due to the shift in electricity mix (Figure 69). Additional carbon savings are made via energy efficiency investments reducing overall electricity consumption. In 2040 we estimate that 15.4GT CO_2e per year is being saved between both our scenarios. Two thirds of these savings relate to investments into solar PV and onshore wind while the remaining third is due to energy efficiency investments.

However, it needs to be highlighted that a large gap exists in carbon intensity measured in CO_2/kWh between different regions, as seen earlier in Figure 19 and Figure 20. In emerging markets regions such as China and India, given their relative size in emissions and their coal-weighted electricity mix, carbon policy can make a greater impact.

Carbon Pricing: The Cost of Action or the Cost of Avoided Liabilities?

As discussed earlier, if it is more expensive to follow a low carbon route (which our analysis logically says that it is) then some form of incentive or penalty needs to be imposed to incentivize that low carbon behavior (or vice versa).

The most widely understood approach is by putting a 'price' on carbon emissions which dis-incentivizes countries, companies, institutions or individuals to emit carbon, thereby encouraging them to use less energy, or to generate or use lower carbon energy. Moreover a carbon price naturally directs investment towards the most cost-effective abatement projects first.

There are two different ways to think about a socially acceptable way to price carbon emissions:

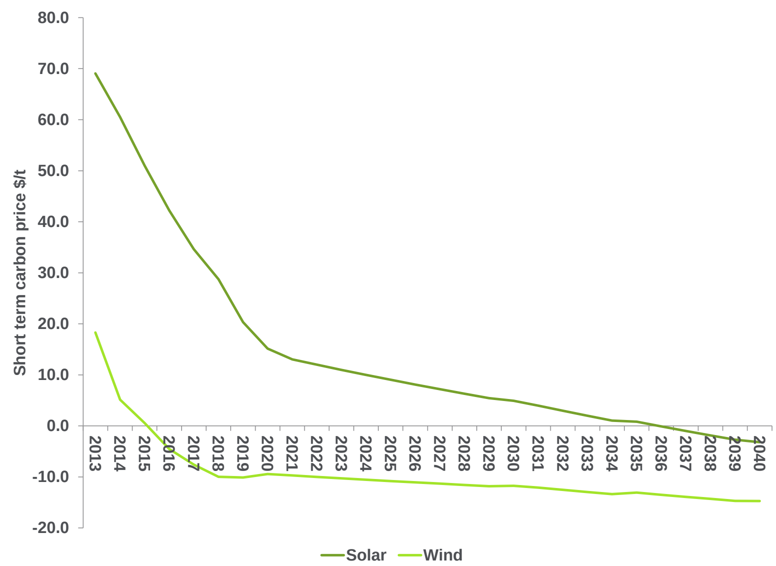
1. Analyze the investment required to reduce carbon emissions, and to tax carbon emissions accordingly to fund these investments.

2. Estimate the liabilities associated with carbon emissions and tax carbon emissions to offset those liabilities.

As seen earlier, we estimate that a transformation into a carbon-light power market could cost society 'only' an additional $1.1 trillion out to 2040. Were we simply to divide this figure by the carbon emissions, this would imply a surprisingly low implied carbon price of just $4/t of CO_2 needed to fund the power market transition between both our Citi scenarios. This figure is so low because as renewable energy becomes cheaper than conventional in later years, there is effectively a net saving to using it, and hence simplistically a 'negative' carbon price in later years which is clearly non-sensical. Moreover, a carbon price that 'reduces' over time is also counterintuitive. Clearly if a carbon price incentivizes an entity to address the most cost-effective abatement opportunities first (the "low-hanging fruit") then by definition as each ton abated becomes more expensive, a higher carbon price would be needed to incentivize that action. Hence, we recognize that a differentiated carbon price might be needed at different points in time (depending on progress) and across different regions in order to incentivize investment into renewable power and 'fund' a lower carbon future.

In practical terms, in earlier years when particularly solar PV is more expensive than conventional fuels, society would need to impose carbon prices which are high enough to level out the playing field. With the rapid fall in the cost of electricity from renewables we anticipate solar PV to be competitive with conventional fuels by 2030 and hence there is theoretically no need for further incentives via a carbon price in the power market alone, as shown in Figure 71.

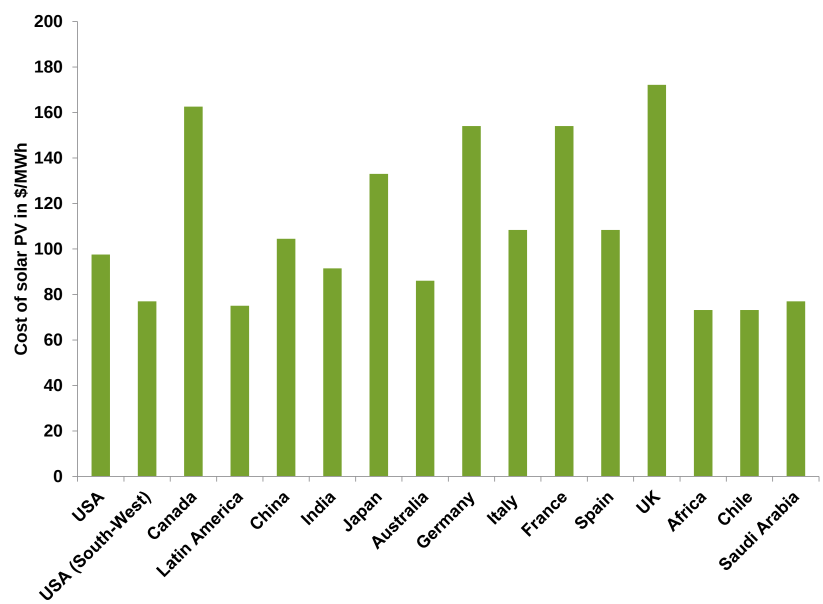
Figure 71. Short-Term Carbon Price Required to Incentivize Investment



Source: Citi Research

It is important to highlight though just how much the economics of renewable energy varies across the world. For example the cost of solar PV electricity is very sensitive to sunshine, which varies drastically across regions (Figure 72).

Figure 72. Solar PV Cost of Electricity Generation Across Different Regions – Citi Projections for 2015



Source: Citi Research

Therefore, the speed of investment and deployment are likely to vary geographically at any given carbon price. As discussed earlier in this report, we view a single 'global' carbon price (or market) as being an unlikely outcome from COP21 in Paris, rather that countries will adopt their own mechanisms based on their own energy demand, growth, mix and resources, mechanisms which may or may not be inter-tradable via mechanisms such as the CDM or JI.

A Word on the Potential of Solar and Energy Storage

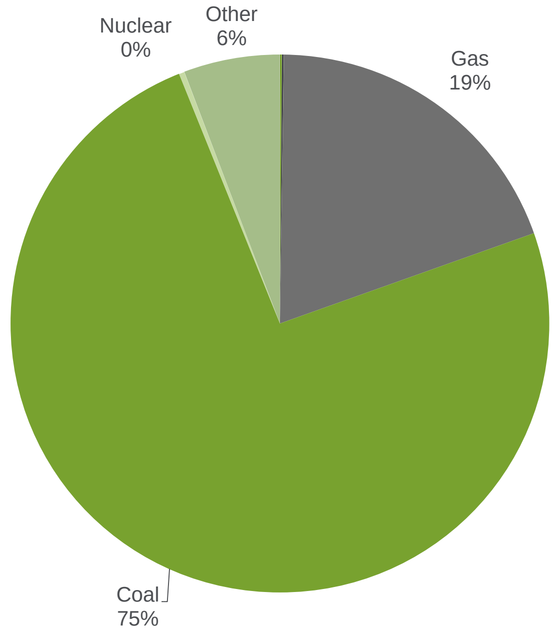
Solar is already competitive at the domestic level in various countries where irradiation (sunlight levels) and residential rates are high. Solar has almost zero variable cost, with most of the cost upfront capex. In our first Energy Darwinism report, we highlighted a case study of Germany which showed how annual solar installations grew from 1GW in 2007 to 7.4GW in just three years. The problem with the expansion of solar (and a criticism of the LCOE approach) is that solar only generates electricity at certain times and therefore conventional plants are still required to cover the demand at other times. This intermittency is the key drawback to solar making storage the 'holy grail' to the solar story; in the longer term it could have an even more dramatic impact on the electricity markets (for more information refer to Battery storage – the next solar boom? and Energy Darwinism II).

Battery storage is starting to become a reality, with the introduction of Tesla's Powerwall, a wall-mounted rechargeable lithium-ion battery. According to Tesla, the battery is designed to enable load shifting by charging during times when demand is low, and discharging when demand is high. The battery can also store solar power generated during the daytime for use at night. It is available at 7kWh or 10kWh and the costs start at an estimated $3,000. The jury is still out on the economics of the product, with it being more economical in certain countries. However, since Elon Musk's announcement on the 30th of April, Tesla has taken orders worth roughly $800 million in potential revenue (Source: Bloomberg - Tesla's Battery Grabbed $800 Million in its first week). Even if you disagree with the economics, it is hard to deny the fact that energy storage could have a huge impact on the electricity market with an increase in investment in solar over the next decade. This technology could be enormously disruptive for utility companies, as highlighted extensively in previous publications such as Let the Survival Game begin as Lost Decade Takes Hold.

Fossil Fuels

Coal-fired plants are the largest single emitters in the power market, making up 40% of the current energy mix. However, coal's high abundance and low price has historically made it the fuel of choice for many countries. In terms of LCOE coal currently represents the most competitive source of electricity generation.

Figure 73. Coal Emits Nearly Three-Quarters of All GHG Emissions in the Power Market



Source: Citi Research

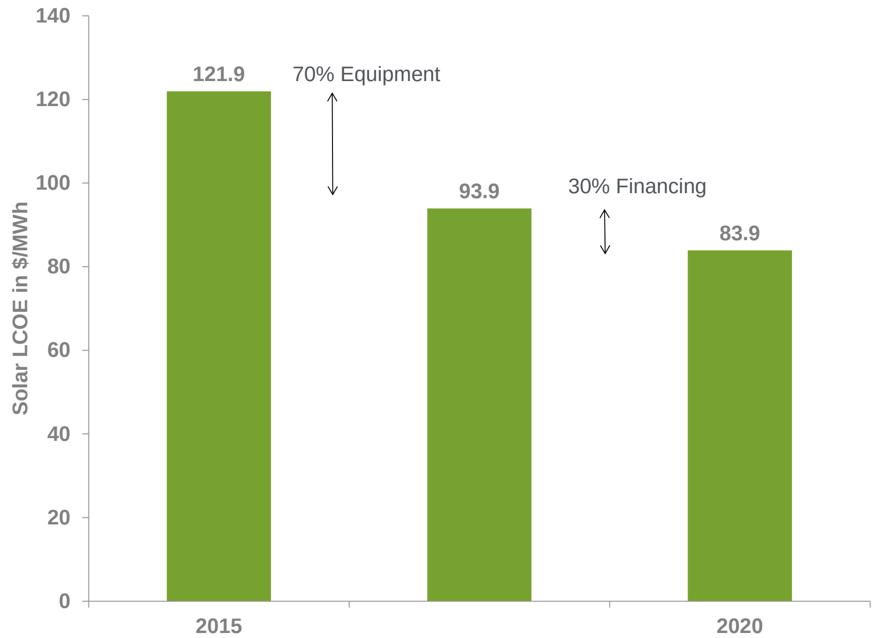
Since coal is the most carbon-heavy fuel, a tax on CO_2 emissions would have a material effect

Given coal is also the most carbon-heavy fuel, any carbon price imposed on emissions would impact the economics of the coal-fired plants the most, whilst gas plants would be less affected by a carbon tax due to their lower carbon emissions per terawatt-hours (TWh) produced.

Global Power Market Outlook 2020: Updating the Energy Darwinism Curves

Since our Citi GPS Energy Darwinism report in 2013, one of the most striking developments in power markets has been the emergence of yield vehicle structures (yieldcos) which finance project equity; this development has reduced the cost of capital for renewables projects significantly.

Figure 74. LCOE Decline Driven by Equipment Cost Reductions and Financing Cost Reductions



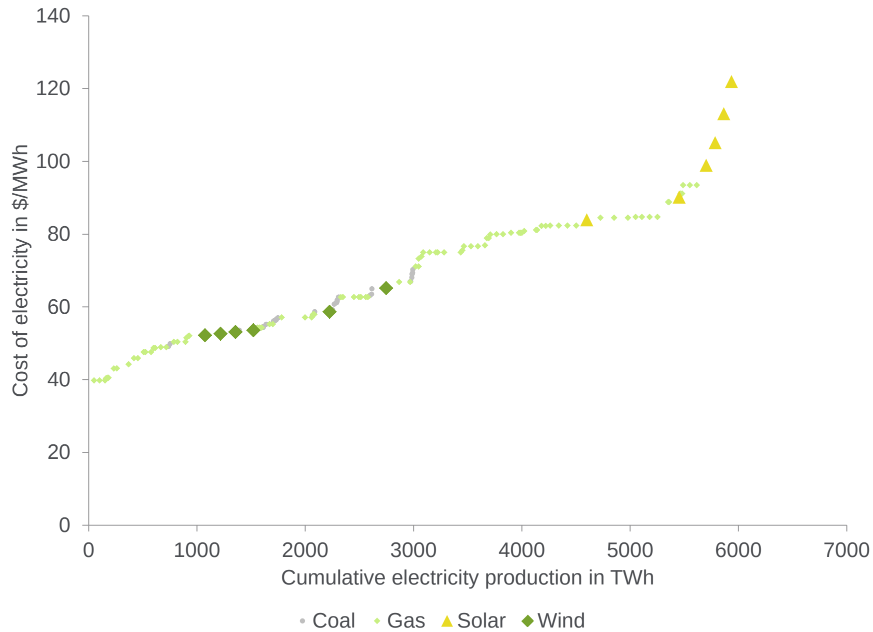
Source: Citi Research

Yieldco's could drive down the cost of capital in the renewable space

We anticipate that the acceptance of yieldcos in the renewables space will further drive down cost of capital via two channels: (1) reducing cost of equity as more equity and income investors become comfortable with the yieldco risk profile and (2) project developers and equipment providers building a track record under the public eye. This development could also reduce spreads on debt project financing. We estimate that the weighted cost of capital for renewables projects can be reduced by another 1% by 2020 down to 4% leading to further reductions in cost of capital.

Our updated 'Energy Darwinism' curve is shown in Figure 75; for a full understanding of how this integrated global energy cost curve is derived, and its implications see the original 'Energy Darwinism' report.

Figure 75. Updated 2020 Energy Darwinism Curve

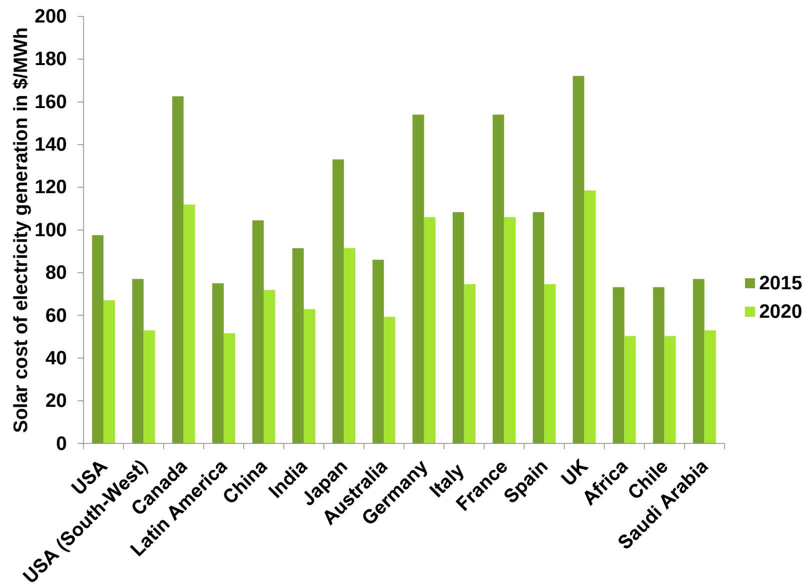


Source: Citi Research

In 2020, we anticipate wind energy to be fully competitive with conventional fuel, even on supercritical coal capex and efficiency assumptions. Gas is very sensitive to the cost of gas extraction per project - at the lower gas band around $1-$2.50/MMBtu it becomes difficult for wind to compete.

While better financing conditions provide a boost to the solar cost of electricity generation and competitiveness by 2020 we still anticipate solar costs to be above $80/MWh. However, solar energy costs are very sensitive to irradiation with notable regional differences; in very sunny regions such as Africa, Chile, and Saudi Arabia, solar could compete on competitive terms with (unsubsidized) conventional fuels. (See Figure 76)

Figure 76. Solar LCOE Across Regions



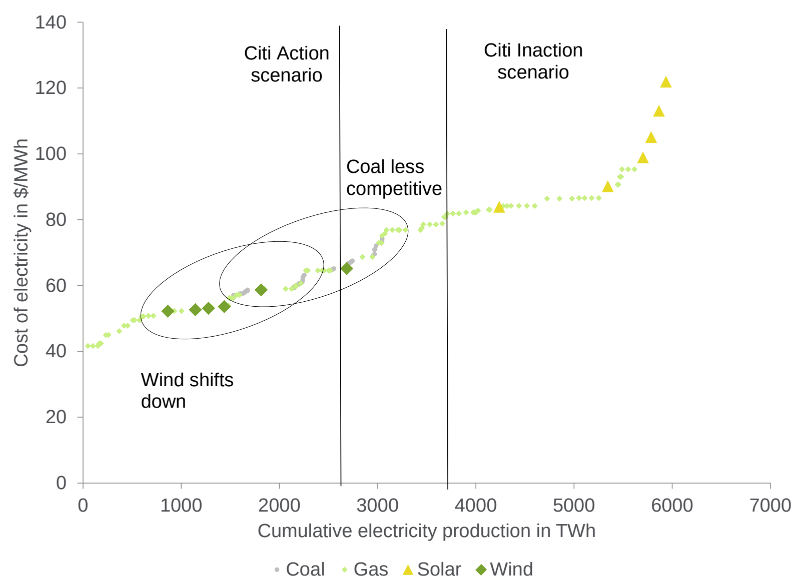
Source: Citi Research

Carbon Pricing: Game Changer for Coal?

Coal would be mostly affected by a carbon price of $4 tonne of CO_2

If we were to overlay the very low $4/t carbon price over our original energy Darwinism curve we find that the coal section of the curve is unsurprisingly most affected. Coal has the highest emission ratio per unit of energy production and a carbon price of $4/t would shift the coal projects on the curve up by about $4/MWh. This would render many coal projects less competitive against low cost gas and wind power. As outlined in our long term/short term carbon price discussion many solar projects would still be uncompetitive at these carbon prices.

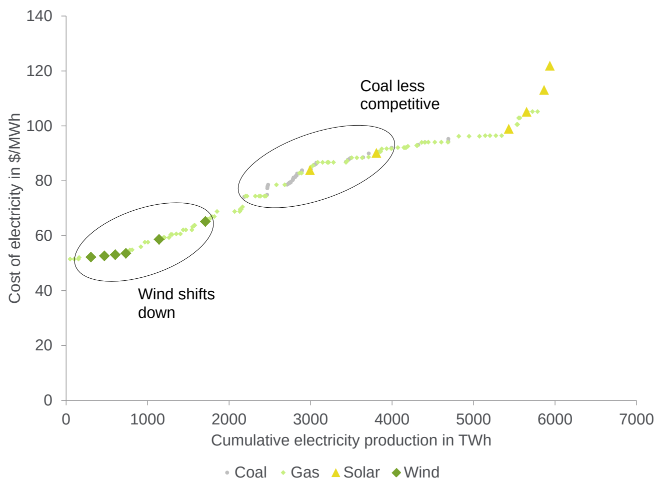
Figure 77. Darwinism Curve with Minimal Carbon Pricing



Source: Citi Research

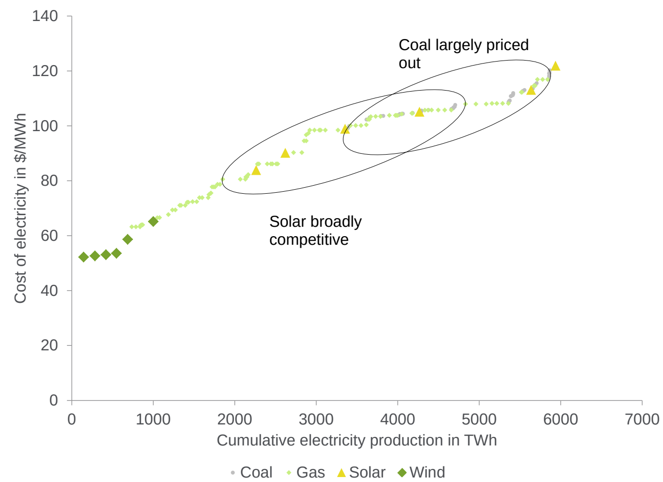
A more relevant scenario would be to apply shorter-term carbon prices to the Energy Darwinism curve. Figure 78 and Figure 79 show the Darwinism cost curves with a $25/t and a $50/t carbon price. As before, coal is impacted most negatively impacted becoming amongst the most expensive generation options at $50/t, and a questionable choice at $25/t, especially given the life of a coal plant is potentially 40 years. Gas continues to span the length of the curves, though clearly assets at the upper end of the curve are pushed even further up the curves. Obviously wind and solar are the big beneficiaries, with wind in particular becoming the lowest cost option at $50/t (and amongst the lowest at $25/t). Solar remains expensive, though at $50/t moves into the second quartile of the cost curve.

Figure 78. Energy Darwinism Cost Curve Out to 2020 at a Carbon Price of $25/t



Source: Citi Research

Figure 79. Energy Darwinism Cost Curve Out to 2020 at a Carbon Price of $50/t



Source: Citi Research

We would highlight that these curves only incorporate incremental energy assets potentially coming onstream between now and 2020, and hence there are only five years of cost reductions shown for solar. Given the dramatic learning rates of around 20% discussed earlier for solar, as time goes on, solar should continue to aggressively reduce in cost, and longer term curves are likely to see solar continue its inexorable move down the curve.

As discussed in the original energy Darwinism report, significant quantities of conventional assets at the upper of the cost curve are in our opinion likely to become stranded. Adding a material cost of carbon to energy will only exacerbate this issue, and is likely to 'strand' a significantly greater proportion of conventional assets, and issue examined in much greater detail in a later chapter.

Drivers of Change (2): Energy Efficiency

Highlights

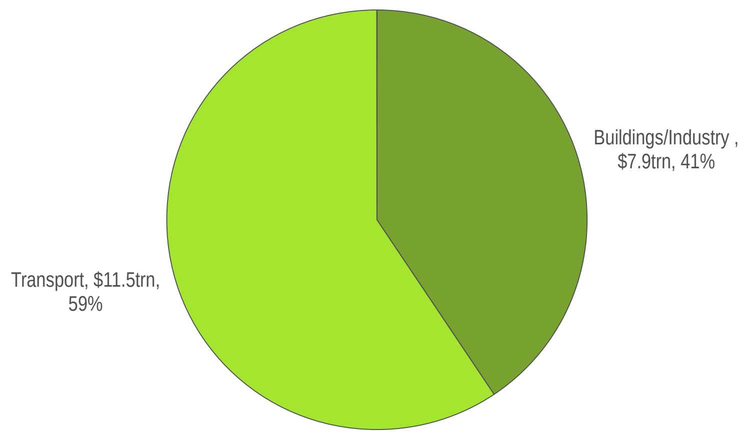
- Our Citi 'Action' scenario entails a total spend on energy efficiency of $19.4 trillion between 2015 and 2040, almost two thirds of which we expect to take place in the transport sector.
- Transportation emissions were estimated at around 7GT of CO_2e per year, representing approximately 14% of total GHG emissions in 2010, and 23% of total energy-related CO_2 emissions in 2013. The majority of the emissions are related to the oil used in road transport.
- Transport emission regulations are being widely adopted, with increasingly stringent miles-per-gallon targets being set globally.
- These efficiencies are expected to be achieved via technological advances such as turbochargers, direct injection, start/stop systems, thermal management, lightweight materials, low resistance tires and transmission technologies.
- BP estimates that energy efficiency measures could result in only a 30% overall increase in fuel usage, despite a potential doubling of vehicle fleets.
- While oil is likely to continue to dominate transport fuels out to 2035, other propulsion technologies such as fuel cells, natural gas, and electric vehicles/hybrids are also likely to play an increasing role in reducing emissions. The imminent launch of new models using alternative technologies from several high profile manufacturers could also add a boost to rates of adoption that have so far been relatively slow.

Transport-Related Emissions

An $11.5 trillion investment would be required in the transport sector

While the previous chapter on the power market transformation touched on the associated energy efficiency spend, 60% of the $19.4 trillion investment in energy efficiency between 2015 and 2040 in our 'Action' scenario will occur in the transport segment (Figure 80). In this chapter we examine that investment and its implications.

Figure 80. Energy Efficiency Spend Between 2014 and 2040 by Activity



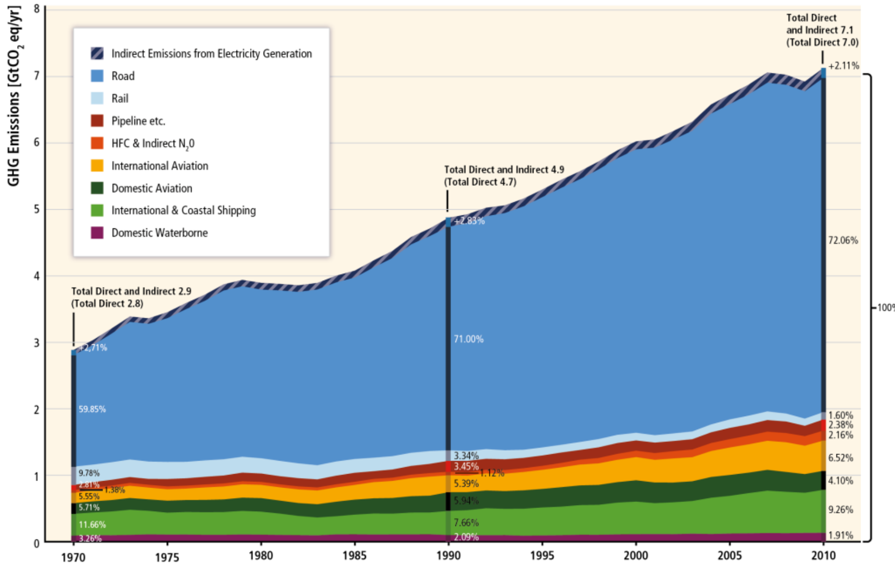
Source: Citi Research

Energy efficiency policies, especially in transport, should be considered an extremely important mechanism for meeting climate change objectives. These relate to actions such as investments in low resistance tires, lightweight materials and direct fuel injection; however energy savings from fuel switching (for example from using an electric vehicle rather than a gasoline one) are not counted as an energy efficiency investment, even though in practice they do increase the overall efficiency of the system.

In 2010, GHG emissions from the transport sector were estimated at 7GT CO_2e. Emissions from this sector, dominated by oil for road transport, have increased by 1.7% per year on average since 2000, but with different underlying regional trends.[15]

[15] IEA (2013)

Figure 81. Transport- Related Greenhouse Gas Emissions from 1970 to 2010



Source: Sims at al. (2014)

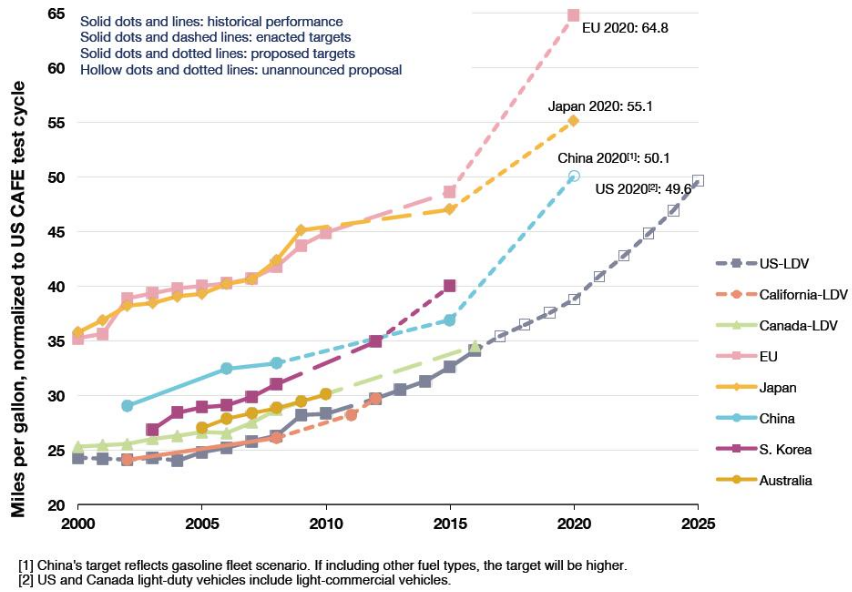
The transport sector has seen a substantial increase in global growth in the past two decades, in the form of increased vehicle ownership and energy use in all transport sectors. However to help mitigate the environmental impacts, many countries have developed transport sector policies to improve the energy and environmental performance of vehicles and fuels. Citi has undertaken a detailed analysis on how regulations on fuel economy and the transport sector in general are changing the market for energy efficiency engine technologies.

Are Emissions and Fuel Targets Propelling the Car of the Future? Which Technologies are Estimated to Grow?

Emissions regulations in the transport sector are expected to increase over time

The introduction of regulations together with changes in consumer demand has compelled automakers to pursue development strategies that focus on fuel economy and a reduction of emissions. Figure 82 below shows the emissions regulations including historical performance together with enacted and proposed targets in different regions up to 2025.

Figure 82. Emissions Regulations: Gram CO_2 per kilometer to 2025

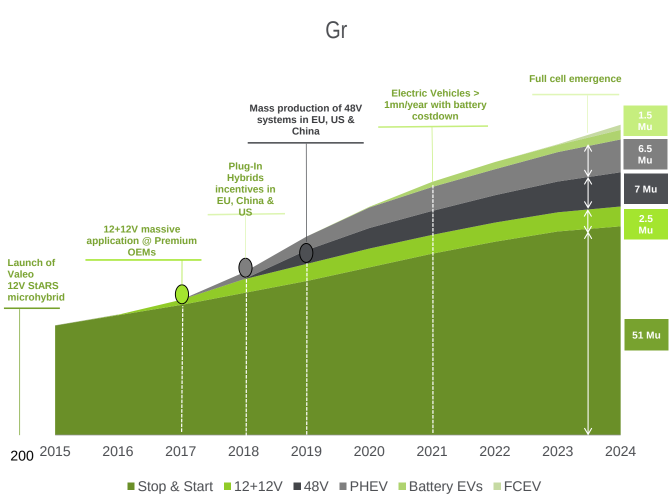


Source: International Council on Clean Transportation, Citi Research

'Workhorse' powertrain technologies will provide the high growth in transport-related energy efficiency sector

These global regulatory regimes are generally in place up to the latter part of this decade. However, even when taking into consideration the significant strides that have already taken place in emerging markets, we believe that many of the high-growth opportunities in transport-related energy efficiency will likely come from "workhorse" powertrain technologies. Figure 83 and Figure 84 below show the proposed growth in engine technologies together with the CO_2 savings and market growth potential of different engine and transmission technologies.

Figure 83. Growth in Engine Technologies



Source: Valeo

Figure 84. Overview Technologies, CO_2 Saving and Market Growth Potential

	Technology	CO2 Saving	Market Growth (2014-2024)
Efficient Engines	Turbochargers	10%	6%
	Direct Injection	10% - 20%	9%
	Variable Valve Timing	1% - 5%	8%
	Thermal Management	Significant	27%
	New Combustion Techniques	Slight	21%
Efficient Transmissions	Automatic Manual Transmissions	7%	8%
	Electric Clutch	7%	10%
	Dual Clutch Transmissions	10%	12%
	Continuous Variable Transmissions	7%	4%
Efficient Engines	Stop Start	7%	11%
	Mild Hybrid	25%	36%
	Full Hybrid	40%	17%
	Plug In Hybrid	70%	33%
	Electric Vehicle	100%	18%

Source: Company Data, Citi Research

Direct injection and start/stop systems can reduce CO_2 emissions by an extra 10-20%and 7% respectively

An example of an efficient engine is a direct injection system which allows fuel to be injected into the engine combustion chamber at a highly pressurized level thereby controlling more precisely the amount and timing of fuel directed into the engine, rendering the engine more efficient. Direct injection often works with turbochargers, reducing CO_2 emissions by an extra 10-20%. European auto-parts manufacturer Valeo believes that gasoline direct injections engines should have a compound annual growth rate (CAGR) of around 9% to 2024. Penetration rates are currently about 30-35% in Europe and 31% in North America. Other examples include Start/Stop systems which could reduce CO_2 emissions by 7%, and thermal management which relates to the monitoring and influencing of the heat of the engine which can contribute significantly to the dynamics and, as a result, has the potential to be one of the fastest growing areas for powertrains (CAGR of ~27% as estimated by Valeo). Advances in transmission technology such as automated manual transmissions and dual clutch transmissions are also instrumental to the improvement in fuel economy for internal combustion engines. For more information on different engine and transmission technologies please refer to Citi GPS report Car of the Future II.

Figure 85. Companies Involved in Efficient Transmission Technologies

"Workhorse" Technologies		Transmission Technologies	
Product Category	Select Companies involved	Product Category	Select Companies involved
Direct Injection	Delphi, Continental	Automated manual transmissions	Aisin, BorgWarner
Low Resistance Tires	Continental, Bridgestone, Goodyear, Michelin	Continuously variable transmissions	Aisin, JATCO
Turbochargers	Honeywell, BorgWarner, Cummins, IHI, MHI	Dual clutch transmissions	Aisin, BorgWarner, Getrag, ZF
Variable Valve Lift & Timing	BorgWarner, Denso		
Thermal Systems & HVAC	BorgWarner, Mahle, Visteon, Denso, Delphi		
Torque Transfer (Driveline)	American Axle, Magna, BorgWarner, GKN, JTEKT		
Stop/Start	Johnson Controls, Denso, Valeo, BorgWarner		

Source: Company Reports, Mezler Engineering Services, Citi Research

Non-Conventional Technologies: Can these Technologies Grow in the Near Future?

A key question is whether non-conventional technologies such as electric vehicles (EVs), fuel cells and compressed natural gas (CNG) vehicles can also make sufficient advances, gain acceptance, and cause a market tipping point. We think that due credit should be given to these unconventional technologies; however, it is important to highlight that disruptive change in the automotive industry does not occur overnight, given long product cycles, capacity requirements and high costs.

Zero-tailpipe emissions could be an important selling point of electric cars especially in countries with high air quality pollution.

From an operating cost perspective, EVs remain superior with a fuel cost-per-mile of only $0.04, which is lower when compared to CNG ($0.07) and conventional gasoline cars, even at current prices. EV's offer maintenance savings from the absence of required oil changes, and have improved performance thanks to their unique torque characteristics. Even though there have been debates about well-to-wheel emissions, the zero tailpipe emission selling points of these vehicles are a powerful consideration for both consumers and regulators. Costs, long charging times and infrastructure remain the greatest barriers to mass adoption, even with tax incentives. While sales of lower-priced US electric cars have been tepid over the years, the major test for EVs will be held in 2017 with the debut of electric cars from Tesla and GM, both of which are targeted at the mass market level. While the US may not have seen huge successes so far, in other markets where taxes on motor fuels are significantly higher, there have been greater success stories for EVs. In Norway for example, 1% of the car fleet is now electric.

Battery technology advancements could increase the uptake for EV's

Whilst skeptics will point to the slow pace of battery technology advancements as proof of the future low uptake for EV's, we think that the outlook for these technologies remains bright, though we do acknowledge that the ramp up would probably be slow (still <2% in most markets by 2020). We believe that the race of EVs is very much still on especially if we look at the competitive environment of participants including Tesla, BMW, Nissan and GM. The uptake of EVs is also likely to differ regionally; for example there is currently strong government support for EV's in China, with the government subsidizing more on the BYD E6 than the US government is on Tesla Motors. Even though the oil price has plunged recently, the Chinese government remains committed to reducing its reliance on oil imports and become more energy secure. EVs are not only a solution to this issue, but also form part of the solution to reducing air pollution in China, a key focus for the Chinese government.

There are parallels between the EV market and the solar industry a decade ago; few would have predicted at that time the speed of cost reductions or the level of penetration which solar has achieved. However, as that industry has proved, with the right incentives and investments, industries can change rapidly, and we believe that the EV and battery market offer similar potential to surprise on the upside.

Other fuel switching technologies such as CNG and hydrogen fuel cell systems are also currently being discussed as possible solutions to reduce transport related emissions. CNG is at present confined mainly to commercial fleets, though a small volume of light duty vehicles utilize a bi-fuel approach (gasoline or natural gas can be used to fuel the vehicle). The Boston Consulting Group believes CNG light vehicle volume in the US could grow to over 300,000 vehicles by 2020, up from around 100,000 in 2014. CNG offers a number of advantages including energy security for gas producing countries such as the US, low cost fuel and a 20-30% reduction in CO_2 emissions compared to gasoline cars. The most glaring challenges are infrastructure requirements, energy density and a large cost premium (refer to Citi GPS: Energy 2020: Trucks Trains and Automobiles).

CNG and fuel cell technologies such as the new Toyota Mirai could also have an effect on CO_2 emissions from the transport sector

With regards to fuel cell technologies, the spotlight is on the Toyota Mirai, which was announced at the end of 2014 and should come to market in late 2015. The Mirai takes the electricity created from the chemical reaction in the fuel cell stack between hydrogen and the oxygen in the air, raises its voltage in the fuel-cell boost converter and powers a motor with it. The Mirai costs are lowered as it can use the motors and batteries shared with hybrid cars, annual sales of which exceed 1 million units. Currently, hydrogen is generally extracted from fossil fuels and CO_2 is therefore produced in the manufacturing process. So in order to be called the ultimate 'eco-friendly car' it is imperative that a hydrogen supply system that is CO_2 free is developed. Shell believes that by the end of the century, roads will be almost oil-free and there could be an extensive hydrogen network as wide as the petrol/gasoline infrastructure today serving a majority-hydrogen fleet. This is partly because of the abundance of hydrogen in the atmosphere and because hydrogen cars have a driving range and refueling time equal to gasoline powered cars. They are also lighter than current EVs which are equipped with large batteries (refer to Citi GPS: Car of the Future.

Figure 86. Comparison of Gasoline Engine, HEV, PHEC, EV and FCVs

	Gasoline Engine	Hybrid Electric Vehicle (HEV)	Plug-in Hybrid Electric Vehicle (PHEV)	Electric Vehicle (EV)	Fuel Cell Vehicle (FCV)
CO_2 Emission (Gasoline engine=100)	100	60-75	30	0	0
Safety	◎	Fire (low risk)	Fire (high risk)	Fire (high risk)	Gas explosion
Price ($)	◎	16,000>	30,000>	20,000	50,000？
Battery amount (kWh)	Unnecessary	0.8-1.3	5-15	15-25	Estimated to be same to HEV
Battery power	Unnecessary	Strong	Strong	Modest	Modest
Driving range (Km)	more than 500km	more than 500km	more than 500km以上	200km	more than 500k
Charging time	Unnecessary	Unnecessary	Good	Bad	Unnecessary
Infrastructure	Gas station	Gas station	Gas station Charging station	Charging station	Hydrogen station

Source: Company Data, Citi Research

The successful adoption of fuel cells could depend on the investment in required infrastructure.

We believe that fuel cell vehicles are unlikely to take off for over a decade due to cost and infrastructure requirements. According to Fiat, building the infrastructure for fuel cells could cost up to £50 billion ($78bn) in a country the size of the UK. While that is a large number in absolute terms, in the context of the trillions of dollars being discussed in this report it is relatively small. The US Energy Information Administration (EIA) states that by 2025 sales of fuel cell cars could be no more than 0.05% of total number of cars sold. However, this view is not shared by Toyota, as they believe that fuel cells costs will be cut in half by 2020. That said, by 2030, we believe that sales could pick up and significant growth could be driven by regulations such as the Zero Emission Vehicles Regulation in California, which mandates that 22% of sales of cars by 2025 must be either plug-in hybrids of fully electric/hydrogen cars.

Will a Low Oil Price have an Effect on Energy Efficiency Investment in Transport?

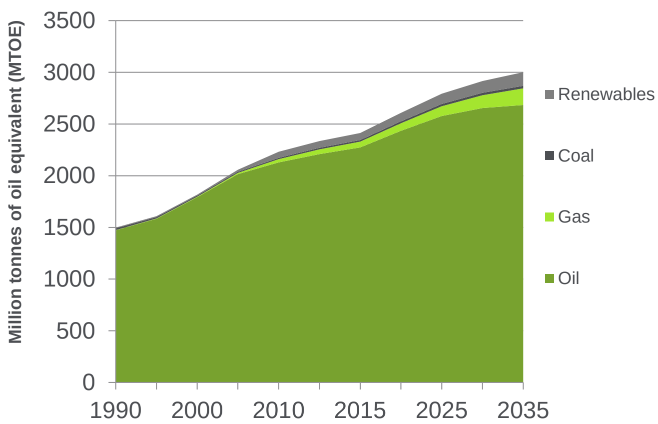
With average gas prices at the pump sliding below $3 per gallon in the US and vehicle mix moving back in favor of larger trucks and SUVs, it seems a good time to discuss US Corporate Average Fuel Economy (CAFE) requirements that will be examined as part of the CAFE ‘mid-term’ review set to take place in 2017. The aim of the review is to evaluate the feasibility of current fuel economy/emissions plans out to 2025. Industry observers wonder whether the stricter standards that ultimately lead to 54.5 miles per gallon by 2025 may be lowered or delayed if lower energy prices continue or government urgency over this matter changes. It appears to us that the substance of the debate would focus on the years 2022-2025 of the program and what the mid-term review can accomplish is to allow automakers to argue for the loosening of this second phase of CAFE standards. Proposals could range from scaling back decade fuel economic targets while introducing stricter, farther out mandates. This could delay the investment in energy efficiency in the US, but ultimately it would not deter it in the long-term. Of course, a new US presidential administration will be in place by the time of the review and that administration’s receptiveness (or lack thereof) to the current plans could represent one of the largest variables in the expected outcome.

What Does This All Mean for Future CO_2 Emissions from the Transport Sector?

Efficiency gains in the transport sector would limit fuel transport demand

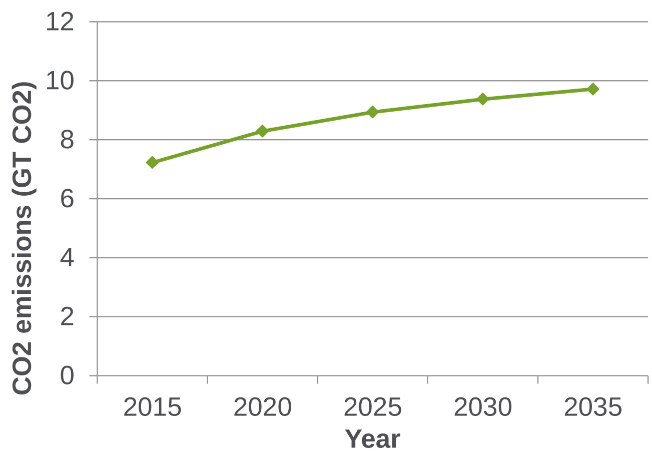
According to BP's Energy Outlook Report, efficiency gains in the transport market could limit the growth in transport fuel demand, with transport demand only increasing by 30% despite a more than doubling of vehicle fleets from 1.2 billion today to 2.4 billion in 2035. They estimate that fuel economy and efficiency gains are likely to accelerate and improve at approximately 2.1% per year between 2013 and 2035 and estimate that oil will continue to be the main transport fuel (89% in 2035), however the share of non-oil alternatives would increase from 5% in 2013 to 11% in 2035, with natural gas estimated to be the fastest growing transport fuel (Figure 87). Even with fuel efficiency improvements of 2.1% per am, this scenario would lead to an increase in CO_2 emissions from 7GT in 2013 to just above 9.5GT of CO_2 in 2035 as shown in Figure 88. This analysis uses IPCC carbon emission factors for different fuels and assumes that the same % mix of gasoline and diesel that is used today is used in the future.

Figure 87. Transport Demand by Fuel Type



Source: BP Energy Outlook, 2015

Figure 88. Transport-related CO_2 emissions based on a 2.1% improvement in energy efficiency and BP's transport fuel mix



Source: Citi Research

Obviously without fuel efficiency improvements, CO_2 emissions would increase at a faster rate, so legislation such CAFE does make a difference. However fuel mix, is also important. For example natural gas is 25% less carbon intensive than diesel (emission factors for CNG and diesel is 56,100 kg/TJ and 74,100 kg/TJ respectively).

Implications (1): Stranded assets

Highlights

- Switching to a low carbon energy future means that significant fossil fuels that would otherwise have been burnt will be left underground. The development of the so called 'carbon budget' has led to the concepts of 'unburnable carbon' and associated 'stranded assets'.

- Emissions contained in current 'reserves' figures are around three times higher than the so called ‘carbon budget’. Some studies suggest that globally a third of oil reserves, half of gas reserves and over 80% of current coal reserves would have to remain unused from 2010 to 2050 in order to have a chance of meeting the 2°C target.

- In financial terms, we estimate that the value of unburnable reserves could amount to over $100 trillion out to 2050. The biggest loser stands to be the coal industry, where we estimate cumulative spend under our Action scenario could be $11.6 trillion less than in our Inaction scenario over the next quarter century, with renewables, wind and nuclear (as well as energy efficiency) the main beneficiaries. While gas suffers a smaller reduction it is still potentially impacted.

- In this chapter we examine the effect on the oil, gas and coal industries, and in particular which assets (typically those at the upper end of the cost curves) which are most at risk of not being developed/used.

- The one potential game changer for the coal industry comes in the form of Carbon Capture and Storage (CCS); while expensive now, if this can be made economically viable, it could carbon-enable huge potential resources. However, the industry is, in our opinion, in a something of an existential race to develop CCS within its survivability timeframe.

- Investors are becoming increasingly active and engaged on the issue of stranded assets, with actions varying from carbon footprinting, realigning portfolios, increasing engagement with fossil fuel companies, or at the extreme banning investments in certain types of companies.

- Stranded assets and unburnable carbon are becoming a significant issue for countries, industries, companies and investors, and focus provided by COP21 in Paris and beyond is only likely to increase attention.

Introduction

One of the major implications of changing to a lower carbon mix, is the amount of fossil fuels that potentially won't be burnt that otherwise might have been. These concepts of “unburnable carbon” and “stranded assets” started to gain broad traction in the investment community in 2012 and 2013, largely driven by analysis from the IEA which stated that:

"No more than one-third of proven reserves of fossil fuels can be consumed prior to 2050 if the world is to achieve the 2°C goal, unless carbon capture and storage (CCS) technology is widely deployed. … Almost two thirds of these carbon reserves are related to coal, 22% to oil and 15% to gas. Geographically, two thirds are held by North America, the Middle East, China and Russia."

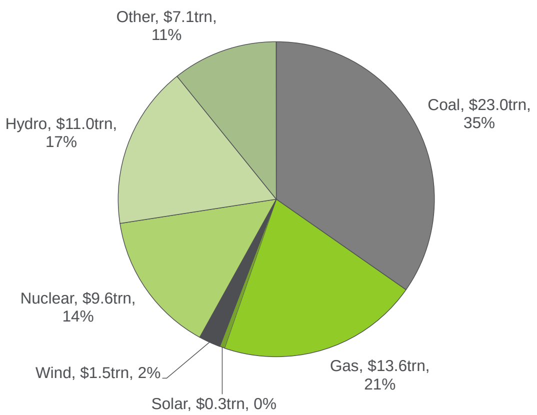
The Risk for Fossil Fuel Producers

Coal is the clear loser under a low carbon scenario

Figure 89 and Figure 90 demonstrate the significant changes in the split of investment in power generation and associated fuel costs between 2015 and 2040 under our two scenarios. The clear loser between the scenarios is coal, which sees its total investment bill fall by some $11.5 trillion over the next quarter century. Gas investment also reduces though by a far smaller amount, $3.4 trillion in total, reflecting the attractions of gas as a lower carbon transition fuel, given its significantly lower emissions per MWh vs. coal.

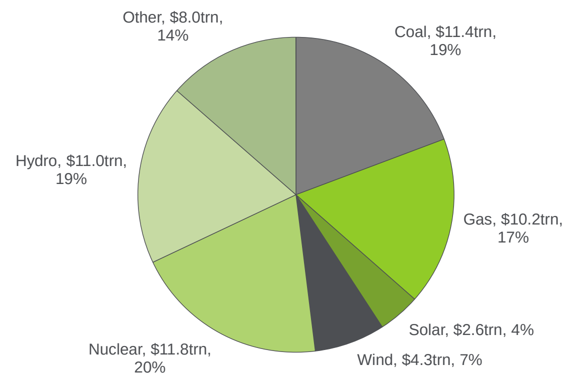
The beneficiaries of the mix shift are unsurprisingly wind and solar which see their investment totals increase by $2.8 trillion and $2.2 trillion respectively. Nuclear is also a beneficiary, with investment increasing by $2.2 trillion over the period. 'Other' reflects generation technologies such as biomass, geothermal, solar thermal, tidal etc., which collectively also see an increase in investment of $0.9 trillion.

Figure 89. Total Spend on Electricity Using an LCOE Approach in Citi's 'Inaction' Scenario. (Total Spend = $66.1trn)



Source: Citi Research

Figure 90. Total Spend on Electricity Using an LCOE Approach in Citi's 'Action' Scenario. (Total Spend = $59.4trn)



Source: Citi Research

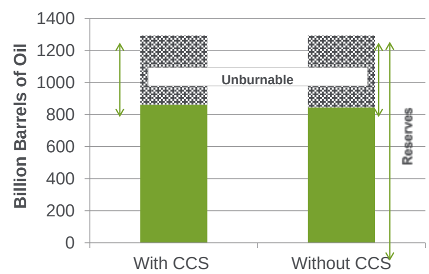
Accordingly, investments in the coal industry (by both companies and investors) based on an assumption of 'business as usual' clearly face higher risks, and in our opinion should be stress tested against either a lower coal demand scenario, and/or one which incorporates a significant carbon price.

While early analysis of unburnable carbon and stranded assets tended to focus largely on the overall proportion of reserves that would be unburnable, greater recent alignment with the investment community has highlighted the risks presented by the potential devaluation of fossil fuel assets. As the original Energy Darwinism report highlighted, an increased focus on the economic viability of potential projects at the upper end of the industry cost curves, either due to lower/different usage profiles or via the impact of a cost of carbon, has encouraged investors to engage with companies about the allocation of capital to such projects. To look at it a different way, the increased risks of non-usage/carbon pricing effectively raises the cost of capital of such projects, potentially thereby making them unviable.

Globally a third of oil reserves, half of gas reserves and over 80% of current coal reserves could be stranded

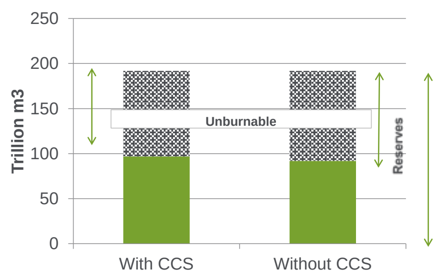
A 2015 report in *Nature* by McGlade and Ekins[16] summarizes the current thinking on 'carbon budgets', and goes on to assess the geographical distribution of fossil fuels that might be unused in a 2°C scenario. The study states that for a 50% chance of limiting warming to 2°C, cumulative emissions between 2011 and 2050 must be limited to ~1,100 gigatonnes of CO_2. Figure 91, Figure 92 and Figure 93 present the findings of this study with estimates of fossil fuels left unburned under two scenarios (a) without CCS and (b) with CCS. Reserves in figures below are defined as a subset of available resources that can be recoverable under current economic conditions and which have a specific probability of being produced. Emissions contained in present estimates of fossil fuel reserves are around three times higher (~2,900GT) than the 'carbon budget', while consumption of all estimated remaining fossil fuel resources would generate emissions of ~11,000GT. The results show that globally a third of oil reserves, half of gas reserves and over 80% of current coal reserves would have to remain unused from 2010 to 2050 in order to have a chance of meeting the 2°C target.

Figure 91. Total and Unburnable Oil Reserves



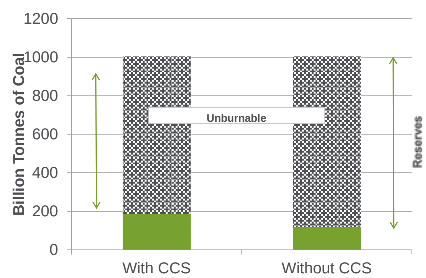
Source: McGlade et al. (2015),Citi Research

Figure 92. Total and Unburnable Gas Reserves



Source: McGlade et al. (2015), Citi Research

Figure 93. Total and Unburnable Coal Reserves



Source: McGlade et al. (2015), Citi Research

However, volumetric figures of barrels, cubic meters and tonnes are not easy to conceptualize. While these should not in any way be taken as pricing forecasts, were we to apply current prices of say $70 per barrel of oil, $6.50/MMBTU of gas (an average weighted price of US, European and Asian prices) and $70 per tonne of coal, we can view these volumetric figures of unburnable oil, gas and coal resources into $ terms, this being much easier to comprehend. The 'value' of the unburnable fossil fuels resources would clearly change depending on the region where the asset was stranded and the local price of the commodity at that particular time, but this approach hopefully gives some idea of scale, as shown in Figure 94.

The total value of stranded assets would be equal to just over $100 trillion

Summing the averages for each fuel implies a total value of stranded assets of just over $100 trillion. Clearly this needs to be kept in perspective – the vast majority of these assets have not yet been developed and are not on companies balance sheets, but it is still a vast number, and is more important when considering the growth/capex/returns potential of associated companies, and the impact on the economies, balances of payments etc. of the countries where those assets lie.

Figure 94. 'Value' of Potentially Unburnable Carbon Based on Current Average Market Prices

Scenario	Value of unburnable Oil (US$ trillion)	Value of Unburnable Gas (US$ trillion)	Value of Unburnable Coal (US$ trillion)
With CCS	30	22	57
Without CCS	25	24	62

Note: Assumes $70 per barrel of oil, $6.50/MMBTU of gas and $70 per tonne of coal
Source: Citi Research

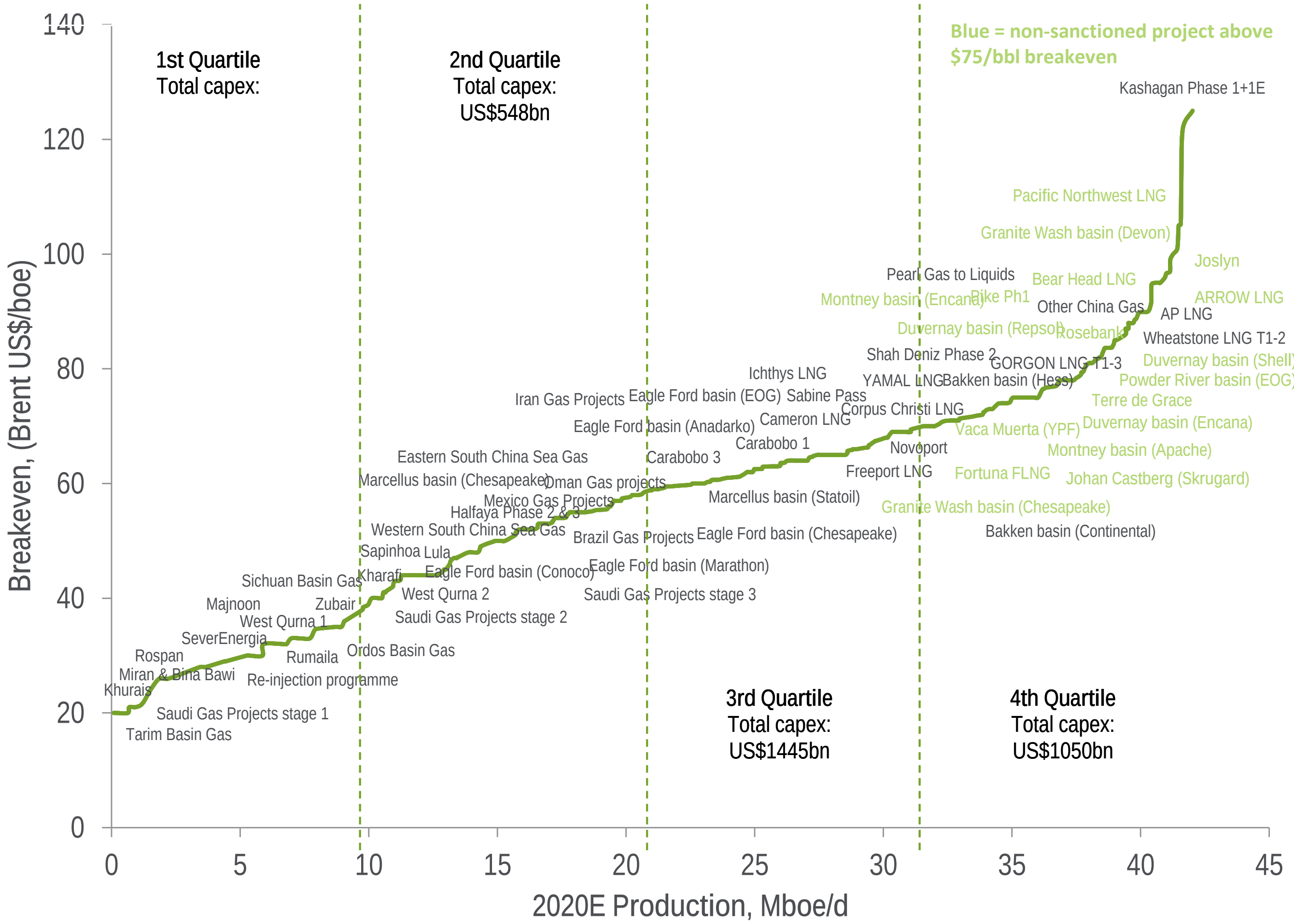
[16] McGlade et al. (2015)

Oil & Gas: Carbon-Stranded, or Economically Stranded?

Due to the current oil price, some assets are already stranded

Citi Research has found that for the first time in a decade, with the decline in oil prices, the supply-curve is beginning to deflate and flatten. The in-depth 325 project analysis (Global Oil Vision) shows that the price environment leaves about 40% of the current investment in oil stranded at prices below $75/bbl on the supply-curve. As companies seek to reposition their portfolio further down the supply curve, sanctioned projects with committed funding will look to embed cost deflation where possible, while stranded non-sanctioned projects without secured funding are likely to be delayed or cancelled to maintain acceptable shareholder returns. Figure 95 highlights the 14 projects in our analysis that remain non-sanctioned above $75/bbl.

Figure 95. Citi's Global Oil Vision Cost Curve for Oil, Showing the 14 Projects that Remain Non-Sanctioned Above $75/bbl



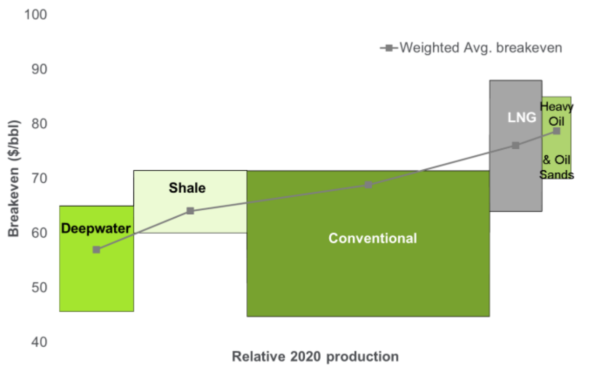
Source: Citi Research, Company Reports

Not All Barrels are Equal

LNG, heavy oil and oil sands are the most at risk

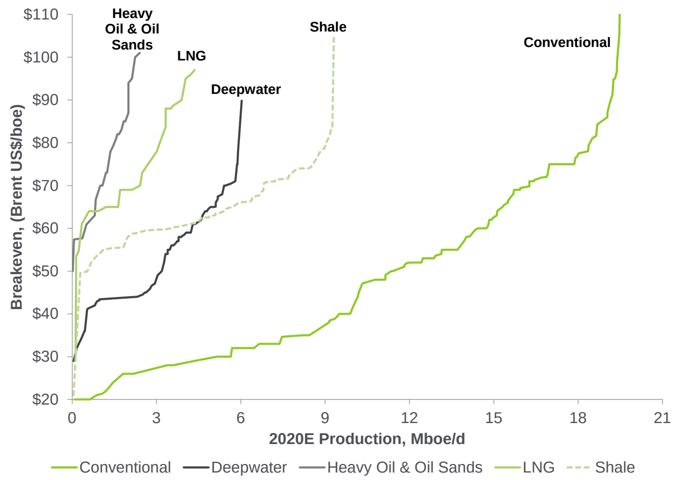
Ongoing sanctioned investments in LNG, heavy oil and oil sands are most at risk of becoming economically stranded high on the cost curve, due in part to the long-dated nature of these developments and their 4-5 year investment lag time before cost deflation of 16-21% starts to improve returns. US shale projects remain the most agile at repositioning themselves on the curve, benefiting from fast cycle times and short payback periods (see Global Oil Services – Investing in a Deflationary World).

Figure 96. LHG, HW and Oil Sands Becoming Stranded While Shale Repositions Down the Curve



Source: Citi Research

Figure 97. Shale Continues to Drive a Wedge in the Supply Cost Curve



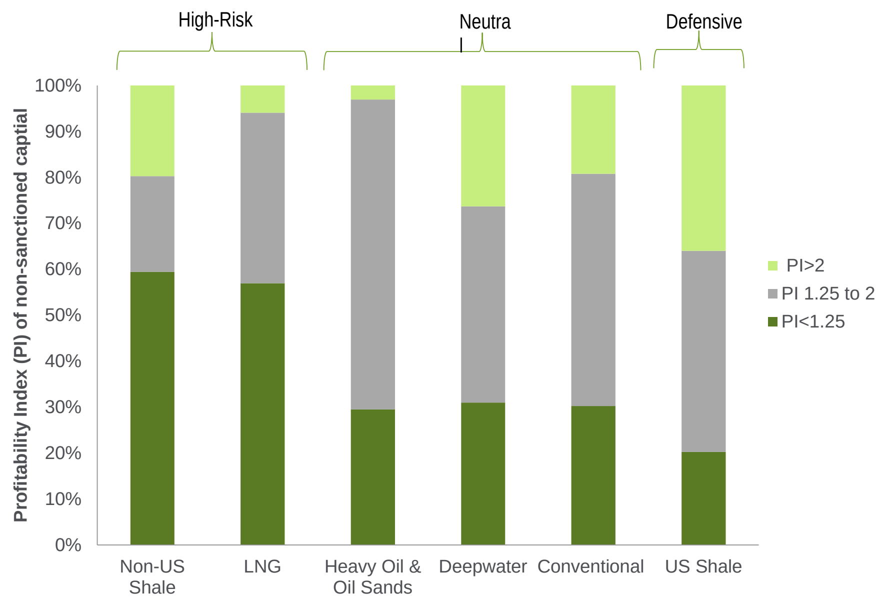
Source: Citi Research

Many of the deepwater tie-backs and hub developments remain attractive in a low oil price environment, improved by the estimated 19% of cost deflation potential expected to be embedded. High capital non-sanctioned deepwater projects are likely to require significant concept development changes or more favorable fiscal regimes to ensure robust economics before sanction; Global Oil Vision shows that 30% of non-sanctioned deepwater is stranded.

Non-Sanctioned Winners and Losers

The decline in oil prices has dramatically altered profitability across all resource types causing companies to announce delays and cancellations to non-sanctioned projects. As the sector begins to reposition investment down the supply-curve, only the most economically robust or strategically important non-sanctioned projects are likely to progress through funding stages in the near to middle term. We would expect companies to mostly progress "Defensive" or top-end "Neutral" projects in their portfolio and look to limit exposure in "High-Risk" projects in resource types like non-US shale and LNG.

Figure 98. Non-Sanctioned LNG and Non-US Shale are "High Risk" with US Shale "Defensive



Note: Defensive = <40% PI<1.25 and >30% PI>2.0, High Risk = >40% PI<1.25 and <30% PI>2.0; Neutral =the rest
Source: Citi Research

The likely consequence will be a shift in weighting of portfolios towards the most economically robust resource types. A decade of cost escalation and the recent decline in oil prices has eroded returns on equity in the sector to a record 29-year low. The reality of the new pricing environment is that it provides a much needed opportunity for the sector to rationalize capital expenditure, embed cost deflation into and reposition portfolios further down the cost curve for future upstream projects.

In conclusion, we expect further cuts in the supply-chain with companies retooling potentially via M&A in the mid-term. While the introduction of government fiscal incentives in the short-term to facilitate production is another clear possibility, this 'unstranding' of economically stranded assets would be at odds with most of the climate goals discussed in this report, and could be argued would not be an efficient deployment of capital. If nothing else, lessons learned from the stranding of assets via the recent fall in the oil price gives food for thought about what the impact of the introduction of carbon pricing (or similar measures from Paris COP21) on higher-cost fossil fuel reserves might be.

Coal: Survival, Extinction, or Both?

The outlook for the coal industry remains challenging; coal is likely to remain an important part of the overall energy mix however cyclically and structurally we think global markets will remain in oversupply capping coal prices and placing significant pressure on the coal mining industry. Its ultimate survival may perversely come down to government intervention, which given the current political backdrop regarding CO_2 emissions doesn't appear likely.

What Has Changed in the Past Two Years?

Seaborne coal prices have decreased when compared to domestic coal prices; and on average around 30% of this industry is losing money

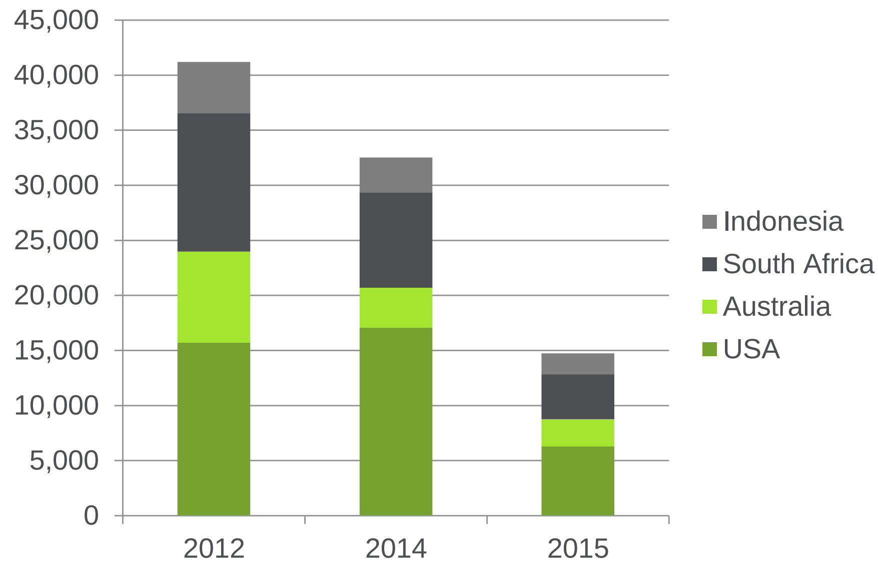
In the original Energy Darwinism report, we expected that coal would be the biggest loser from the shift that was occurring in the energy mix globally. We argued that the biggest impact was likely to be felt in the seaborne market, which is a small percentage of the overall market, as energy importing companies substituted away from imported coal. In the past two years we have seen a dramatic fall in seaborne thermal coal prices, relative to domestic coal prices. On our estimates around 30% of the seaborne coal industry is now losing money on a cash basis.

Figure 99. Seaborne Coal Price CIF Europe and Domestic US US$/

Source: Citi Research, Bloomberg Data

This has placed considerable stress on the coal mining companies; the market value of the listed equities that Citi Research covers has shrunk from around $50 billion in 2012 to around $18 billion today. To date, mine closures, liquidation and bankruptcy have been limited but given our view of the market we think these factors could accelerate.

Figure 100. Market Cap of Listed Coal Companies Under Citi Research Coverage



Source: Citi Research

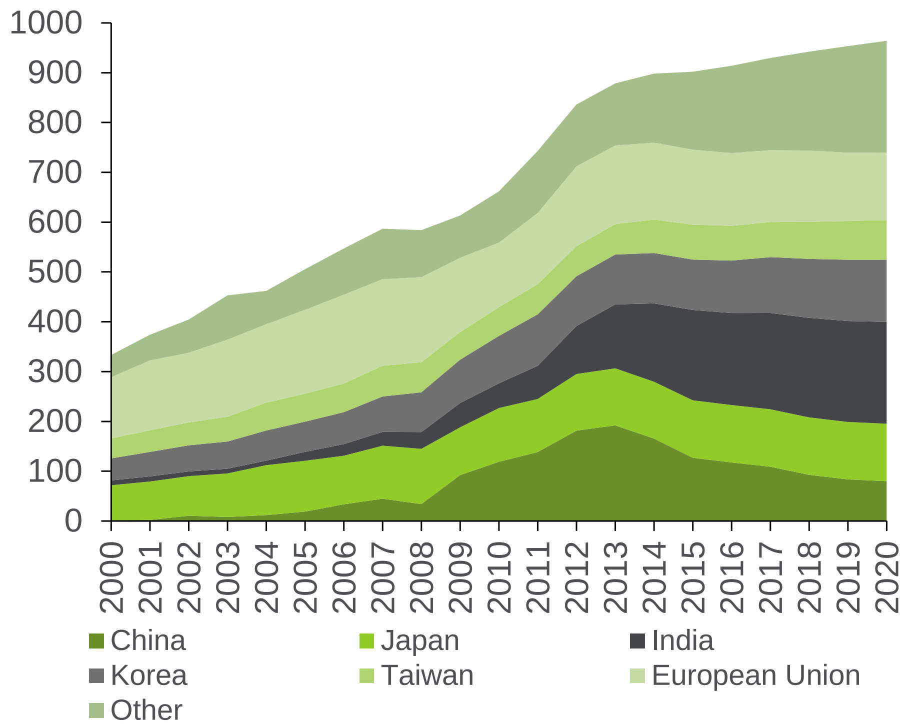
Both investors and governments are beginning to move away from coal

Moreover there has been a shift in investor appetite as regards coal, which has arguably been politically driven. This is best exemplified by the Norwegian government applying a coal screen to its sovereign wealth fund (SWF) investments, a move that is being carefully watched by other investors around the world who increasingly want to make a contribution to addressing climate change (Further Pressure on Coal). The Church of England has endorsed recent comments from the Papacy about reducing greenhouse gas emissions, all of which is leading to continued pressure on the coal industry.

The large coal importing countries have also reacted in the past two years. South Korea is planning to reduce the share of coal in the country's energy mix from 37% this year to 27% by 2029. The government will implement an additional tax rise of around $4.40/tonne across the board, effective July 1, 2015 on the almost 100Mt that it imports, which is around 10% of the seaborne market. In October 2014, China surprised the coal market and introduced an import tariff of 6% for thermal and 3% for coking coal. The China-Australia Free Trade Agreement signed in June 2015 will result in the tax being lowered to 4% from January 1, 2016, to 2% from January 1, 2017 and 0% from January 1, 2018. Coal imported from Indonesia is exempted from import tax due to the China and ASEAN Free Trade Agreement.

We think that India will remain a net importer for some time to come, but to a declining extent over time. Short term, the coal ministry is focused on expediting clearances, bringing in new technology, and improving rail connectivity. This coupled with the auction/allocation of coal blocks provides visibility on India's potential to accelerate coal production. However, the process alone would not enhance coal availability until existing constraints are dealt with. Medium term, we anticipate captive coal production will rise 20% through FY14-20; we now forecast Coal India's volumes to grow at 7% through FY14-20 vs. 2% through FY10-14. A combination of the two should result in India's domestic coal supply growing at ~8% through FY14-20. Our bottom-up demand analysis suggests demand growth of ~7%; imports will follow a declining trajectory over time – with deceleration likely to commence in FY19.

Figure 101. Seaborne Global Thermal Coal Imports by Country – Citi Forecasts (Mt)



Source: Citi Research, Wood Mackenzie

Is Time Running Out for the Coal Industry?

The response of the coal industry so far could be best described as optimistic and hopeful. Optimistic that demand will pick up and prices with it, and hopeful that 'clean coal' technology will become available and save the day. On the demand side we think thermal coal is cyclically and structurally challenged and that current market conditions are likely to persist. This in our view will force the companies to take dramatic actions; the large diversified mining companies such as Rio Tinto, Anglo American and BHP Billiton have either been exiting thermal coal operations or significantly rationalizing their businesses. The pure play or heavily exposed mining companies appear to want to ride out the storm.

Could CCS be a 'game changer' for the coal market?

The 'game changer' and blue sky scenario for coal rests in carbon capture and storage (CCS), though as explained below we think the timeframe for commercial success may be beyond the survival window for a lot of the coal mining companies.

Ironically, the coal industry may need support or bail outs from governments, though the appetite for rescuing the industry both economically and politically appears limited. However, despite the stranded asset issue, coal is likely to remain a backbone in certain regions such as South Africa, where the current power shortages and rolling blackouts suggest that the medium term solution is likely to have to involve coal, the question being how or whether the government will need to incentivize coal production.

Carbon Capture and Storage

Carbon capture and storage (CCS) is often cited as an important technology to allow continued use of fossil fuel resources, particularly coal, in a carbon-constrained world. CCS involves three major steps:

- **Capture:** The separation of CO_2 from other gases produced at large industrial process facilities such as coal and natural gas power plants, oil and gas plants, steel mills and cement plants.
- **Transport:** Once separated, the CO_2 is compressed and transported via pipelines, trucks, ships or other methods to a suitable site for geological storage.
- **Storage:** CO_2 is injected into deep underground rock formations, often at depths of one kilometer or more, where it is permanently stored.

What is CCS?

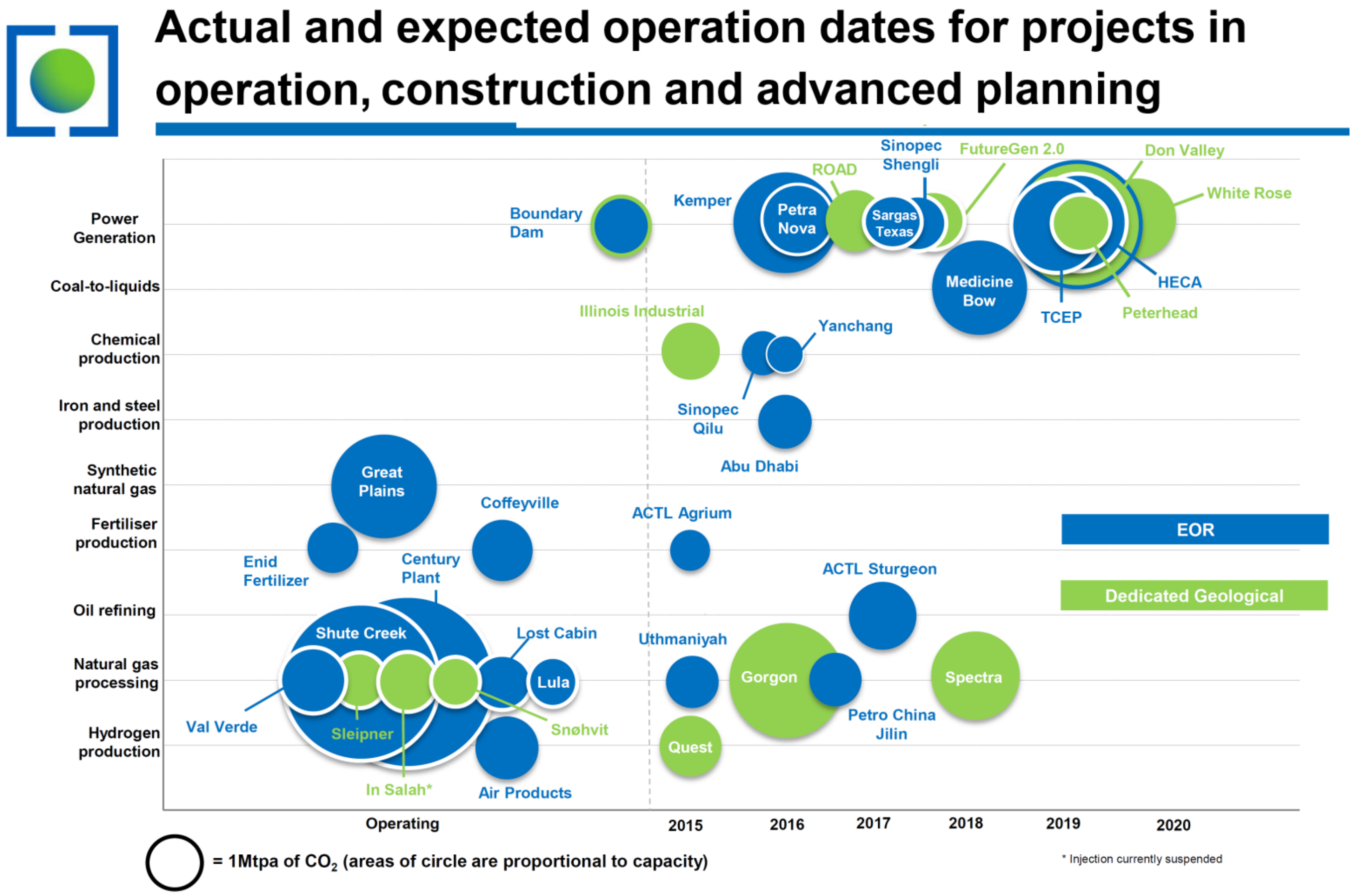
Carbon Capture and Storage (CCS) is a technology that can capture up to 90% of CO_2 emissions produced from the use of fossil fuels in electricity generation and industrial processes, preventing CO_2 from entering the atmosphere. However, it is still at an early stage; according to the Global CCS institute, as of February 2014, there were only 21 active large scale CCS projects in operation or under construction globally, with a combined capture capacity of almost 40 million tonnes of CO_2 per year.

CCS Status

The majority of CCS projects are associated with EOR as it is more cost-effective than geological storage

The Global CCS Institute (GCCSI) has analyzed the status of CCS projects around the world (Figure 102). The majority of projects to date are associated with either enhanced oil recovery (EOR) or with natural gas processing. The recently commissioned Boundary Dam project in Canada has been hailed as a milestone project in the power industry.

Figure 102. Capture Carbon and Storage Projects



Source: Global CCS Institute

Technical Progress, But a Lack of Policy Drivers

CCS is widely seen as being key to achieving the global greenhouse gas emission reductions by 2050 needed to put the world on a path towards limiting warming to 2°C, at lowest cost. This would require substantial deployment by 2030 (i.e. 1.5GT) compared with around 40-50Mt now, rising to ~6GT in 2050. However, if implementation is to accelerate from 2025, project development, including assessment of geological storage sites, needs to accelerate quickly.

However, progress is being made. The Canadian Boundary Dam project (SaskPower) which recently started production, has been hailed as a milestone project. China is progressing the technology, with substantial storage capacity in petroleum basins in the Pearl River and South China Sea areas. In Australia's Surat Basin, Glencore is developing the Carbon Transport and Storage project, currently at a feasibility study stage. As a major coal exporter, Glencore is developing the 120kt per year project to demonstrate to its coal customers that the technology works. The project is able to take advantage of existing Glencore infrastructure in the area (Wandoan mine) to keep costs down.

Carbon prices could provide an incentive for CCS deployment

Despite progress on the technical front, the industry believes there is a need for government policy to support the business case for broad scale implementation. While the fossil fuel industry, particularly coal, has tended to resist carbon pricing developments, ironically the lack of carbon pricing means there has been no business case for large scale CCS deployment.

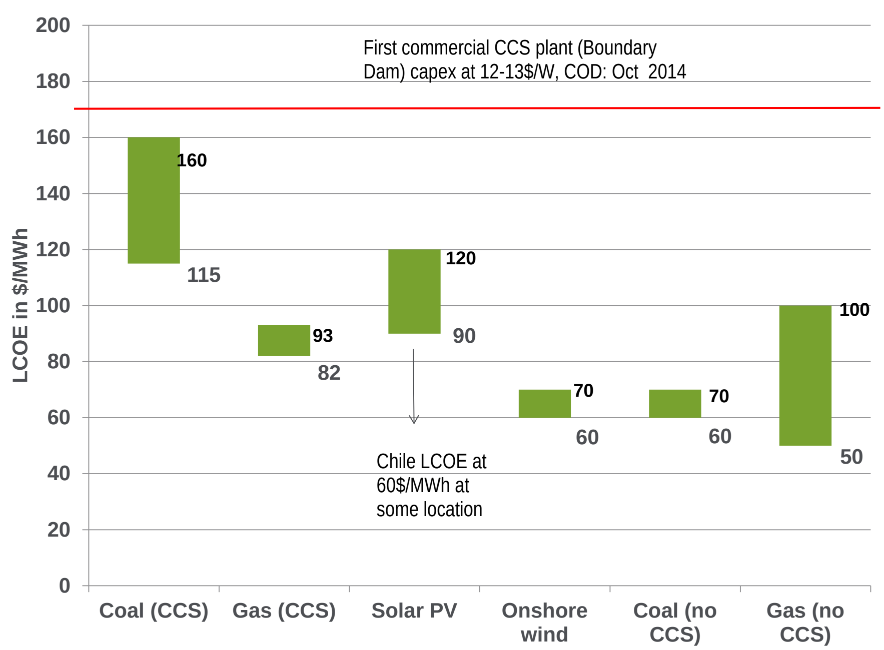
If progress is not made quickly with CCS, it is difficult to see it playing a major role in emissions reductions since other technologies may make sufficient progress to render CCS 'too little, too late'. The concept of "clean coal" may then fail to materialize, further weakening the prospects for thermal coal as a commodity.

CCS Costs

CCS can more than double the LCOE of a coal fired plant

Assessing the cost of CCS is problematic given the limited number of projects and the scale thereof to date. The GCCSI provides some indicative costs as shown in Figure 103, showing that coal with CCS is still significantly more expensive than other technologies. We understand that the CCS estimates shown in the chart are based on US conditions (the Boundary Dam figure is a Citi estimate), and CCS costs will vary with project detail and location. Costs of proving up storage capacity are probably in addition to the costs shown below. However, if the right attention and investment is devoted to R&D and implementation becomes more widespread, there is scope for costs to reduce significantly (as shown by the GCCSI estimates) as has been the case with other technologies.

Figure 103. Comparison of LCOE's for CCS vs. Other Power Generation Technologies



Source: Citi Research, Global CCS Institute

CCS Conclusions

We continue to have reservations about the risk-reward equation for CCS. On the positive side, it represents a potentially enormous game-changer for energy markets; with almost 3000 years-worth of potential coal resources (at current usage rates) if CCS could be commercialized, then in many ways all other bets would be off. If CCS were to materialize on a large scale, it would provide opportunities for companies in the engineering, construction, pipeline and drilling industries, and geological expertise might align with petroleum industry capabilities. Conversely, we harbor reservations regarding the large scale of investment required and long payback periods, which potentially make projects vulnerable if alternative solutions such as renewables, storage or hypothetically algae, become cheaper and more widely adopted in the meantime. Regulatory and political risks obviously remain key factors. We will watch industry progress with interest to see if the needed short-term momentum does in fact increase.

Implications of Paris COP21 for Stranded Assets

While any Paris agreement may well not fully align with the 2°C objective, the outcome is likely to be that countries' commitments to reducing emissions will strengthen over time, with obvious implications for stranded assets in terms of both quantity and timing. Accordingly, while an outcome might not be 'definitely negative', its direction is likely to be clear, and is likely to raise further the risks posed by stranded assets.

How Might Assets Become Stranded?

There are various possible mechanisms by which assets may become stranded, which may affect certain types of assets sooner than others. Some of these effects are already evident in some markets, some may soon become significant, with others emerging in the longer term. We highlight the key possibilities below:

- Regulations could require the closure of certain operating assets, for example old or high emissions power stations.
- Regulatory constraints might add to costs, making assets economically unviable.
- Regulations might be enacted to prevent development or construction of certain new assets.
- Regulation might impose requirements such as emissions constraints, or for example, the adoption of carbon capture and storage, which would increase costs to the extent that potential projects may become unviable.

Hence, market mechanisms such as a price on carbon could make existing or new projects unviable. Demand for fossil fuels could fall as the costs of renewables fall, and technology improves. Local air quality considerations may also play a role in favoring renewables over coal, and regulations may support this.

Markets are connected, so local legislation on CO_2 emissions could affect aggregate global demand for fossil fuels

Given global markets, mechanisms or regulation in one country may of course affect suppliers elsewhere; local regulation in consuming countries will affect aggregated global demand for fossil fuels, with a potential knock on effect on pricing and hence consumption patterns in other markets. These price and weakening demand effects would also depend on (and affect) supply response, because if new projects are abandoned, this may lead to healthier demand and prices for incumbent producers.

Any combination of the above could lead to stranded assets. Certain fossil fuel assets may not be developed, with demand and price forecasts too low (or risk assessments too high) to support project economics as described above. Premature closure of operations could also occur if weaker markets lead to negative operating cashflows.

Types of Stranded Assets

The "stranded assets" concept is already in play; the European power sector has already undergone substantial change in line with the projections of the original Energy Darwinism report. The current focus is on high cost, high emission and long-life undeveloped oil and thermal coal projects, since high-cost long-life projects would be most vulnerable if product demand and prices weakened over time. This includes major new coal provinces such as Australia's Galilee Basin, which would require major investment in new export infrastructure to be developed. In oil, unconventional deposits such as Canadian oil sands and Arctic projects are under particular scrutiny.

Over time, impacts may spread further to lower cost or lower emissions fossil fuels, including currently producing projects. Gas and LNG may initially be insulated as a lower emissions transition fuel, but fossil fuel constraints could ultimately impact these commodities too, perhaps several decades hence.

Investor Approaches to "Carbon Risk" and Potential Stranded Assets

Many long-term broad-based investors believe that climate change is one of the biggest systemic risks they face, as well as presenting one of the largest opportunities. Tackling climate change is seen as being important to the long term health of the economy and therefore to investment returns.

Investor actions typically start with so-called 'carbon footprinting' whereby an asset manager assesses the exposure of funds to carbon, climate change and associated issues. There is as yet no consensus approach to portfolio footprinting; service providers each have their own methodologies, and increasingly investors are considering what approach they might adopt. Typical approaches include Scope 1 (direct) and Scope 2 (indirect) emissions, per unit of revenue or market capitalization. Other approaches may include some forms of Scope 3 emissions (e.g. emissions from customer use of a company's fossil fuel products), while others are exploring more novel approaches. A number of major investors have signed up to the 'Montreal Pledge' (launched at the Principles for Responsible Investment conference in Montreal in September 2014), signatories effectively committing to measure and disclose the carbon footprints of their portfolios. In conjunction with footprinting, asset managers have started to adopt a variety of other responses to the issues of carbon, climate change and potentially stranded assets as follows:

Screening, tilting exposure, engagement and hedging are four ways that asset managers have responded to the issues of stranded assets

- **Screening:** Some investors have applied fossil fuel screens to the "riskiest" types of fossil fuel assets – examples include thermal coal production, coal-fired power generation, and oil sands. They may apply a materiality threshold for exclusion from the fund's universe, while some funds have taken a broader approach to divesting fossil fuel assets.

- **Tilting exposure:** Some investors have adopted or explored ways to "tilt" their portfolios to reduce carbon exposure, based on their own preferred carbon intensity metric, or via the use of "low carbon indices".

- **Engagement:** Some investors prefer to remain invested and to "engage" with companies to better understand their resilience to a lower carbon world and to better understand capital allocation decisions and what scenarios have been explored, or to encourage companies not to allocate capital to the riskier types of fossil fuel projects. Engagement can also include discussion of executive remuneration incentives, given that incentives based on reserves replacement or production growth might encourage allocation of capital to projects at risk of stranding.
- **Hedging:** Investors may hedge their portfolios against stranded asset risk by allocating funds to low emissions or clean technology investment options.

Norwegian Report on Approach to Coal and Petroleum Investments

Perhaps the best public example of an individual fund's consideration and response to this issue comes from Norway. The Parliament has announced its intention to adopt a bill which would exclude the $850 billion (the largest of its kind in the world) Norwegian Government Pension Fund Global (GPFG) from investing in companies which themselves, or through entities they control, base 30% or more of their activities on coal, and/or derive 30% of their revenue from coal.

Investor Groups

As well as individual actions, investors have started to form international investor groups, collaborating to encourage policy makers to provide appropriate signals, emissions pledges and plans to encourage the transition to a low carbon economy, then standing ready to allocate capital towards the transition under appropriate policy backdrops. Key investor groups include:

- The UK/Europe Institutional Investors Group on Climate Change (IIGCC)
- The US Investor Network on Climate Risk (INCR)
- The Australia/New Zealand Investor Group on Climate Change (IGCC).

Other international investor collaborations such as that being launched by the Principles for Responsible Investment (PRI), are designed to address potentially inconsistent corporate climate policy positions, where a company's public statements on its support for action to address climate change appear to be at odds with those of industry associations of which it is a member, or think tanks which it co-funds.

Another emerging initiative is the Portfolio Decarbonization Coalition, whose intention is that institutional investors representing large segments of the global economy will disclose their carbon footprints, and publicly commit to 'decarbonize' a specific portion of assets under management in a particular timeframe. It believes that that this engagement and reallocation of capital into carbon-efficient investments will provide a strong incentive for companies to adapt their own strategies towards lower-carbon activities.

Potential Implications for Companies

Change in investor attitudes could divert capital away from companies or at least influence their strategies

These changing investor attitudes and initiatives have obvious implications for emissions intensive companies, in that it may divert capital away from those companies, or lead to increasing influence on strategy via a process of greater engagement. The latter approach is perhaps best demonstrated in the recent resolutions proposed by investors for the Annual General Meetings (AGM's) of both Shell and BP. These resolutions (which were supported by both boards and duly passed) were related to greater transparency around the climate and carbon risk issues facing the companies. The aim of such resolutions is to encourage energy companies to develop clear strategies around the risks posed by potential changes to the world's energy markets, and to explain how they reflect these strategies in their investment decisions and allocation of capital.

To what extent increased company disclosures defend the status quo, or contribute to better risk management or an accelerating transition to a carbon constrained world, remains to be seen. However, it is clear that large long-term investors are increasingly seeking to be more active stewards of companies they own, and that energy transition is becoming an increasingly significant stewardship issue.

In a material sign that this engagement is having an effect, on June 1, 2015 a group of major European oil & gas companies, namely Statoil, Total, BP, Shell, ENI and BG, jointly issued a letter calling for governments around the world and the UNFCCC to introduce pricing carbon systems. They stated their hope that these systems would create 'clear, stable, ambitious policy frameworks that could eventually connect national systems' – i.e. a global carbon market.

If the COP21 meeting in Paris is successful, it could lead to significant quantities of stranded assets which could fundamentally alter the outlook for the fossil fuel and power industries. Regardless of the outcome of Paris, investor sentiment is changing and cannot be ignored – after all investors provide the capital to companies, and the removal of this capital (or threat of) could either mean that companies couldn't invest, or could only do so at a higher cost of capital, thereby potentially stranding more projects.

Implications (2): Can We Afford It?

Highlights

- This chapter tries to address three key questions

  – What impact would the higher spend required to follow a lower carbon future have on global GDP?

  – Who pays?

  – What would be the distribution of those effects around the world?

- Energy is inextricably linked to GDP, and restricting it, either directly, or by making it more expensive, represents a negative supply shock. Accordingly we need to consider the impact on GDP of the vast investments required into energy.

- Energy as a cost has historically varied between about 3% and 10% of global GDP in primary energy terms, with the upper levels acting as a brake on global GDP growth

- On our analysis, our Citi 'Action' scenario does not require a material increase in the cost of energy as a percentage of GDP, relative to historic levels – in fact the total costs are lower if we incorporate the fuel savings in later years.

- As discussed earlier, there is a limited difference ($1.8 trillion) in the total bill to 2040 between our 'Action' and 'Inaction' scenarios. However, we demonstrate the higher earlier spend on renewables and energy efficiency in the action scenario, which leads to fuel savings later.

- Comparing the in-year differential cost between 'Action' and 'Inaction 'shows that there is a net cost per annum of following a low carbon path until 2025, after which we move into net savings via lower fuel usage. At its worst, this net cost is only around 0.1% of global GDP; in a cumulative sense there is a net cost out to 2035, beyond which there is a net saving; at its worst this cumulative net cost is still only around 1% of current GDP. In the context of the potential liabilities, these seem like relatively small figures.

- In a positive sense, a more diverse energy mix could make future energy shocks less severe, as could the non-fuel nature of renewables. The greater upfront investment in energy could also help to boost growth and act as a partial offset to the effects of secular stagnation being witnessed currently. Lower long-term energy costs as a percentage of GDP could ultimately serve as a significant boost to GDP, especially compared to the potential lost GDP from inaction.

- The issue of who pays remains a tricky issue – future growth in emissions will come from emerging markets, while historic emissions were largely put in place by developed nations. Given that we are all therefore responsible, and would all suffer the consequences of global warming, it seems logical that everyone should play their part; the issue is of course the split.

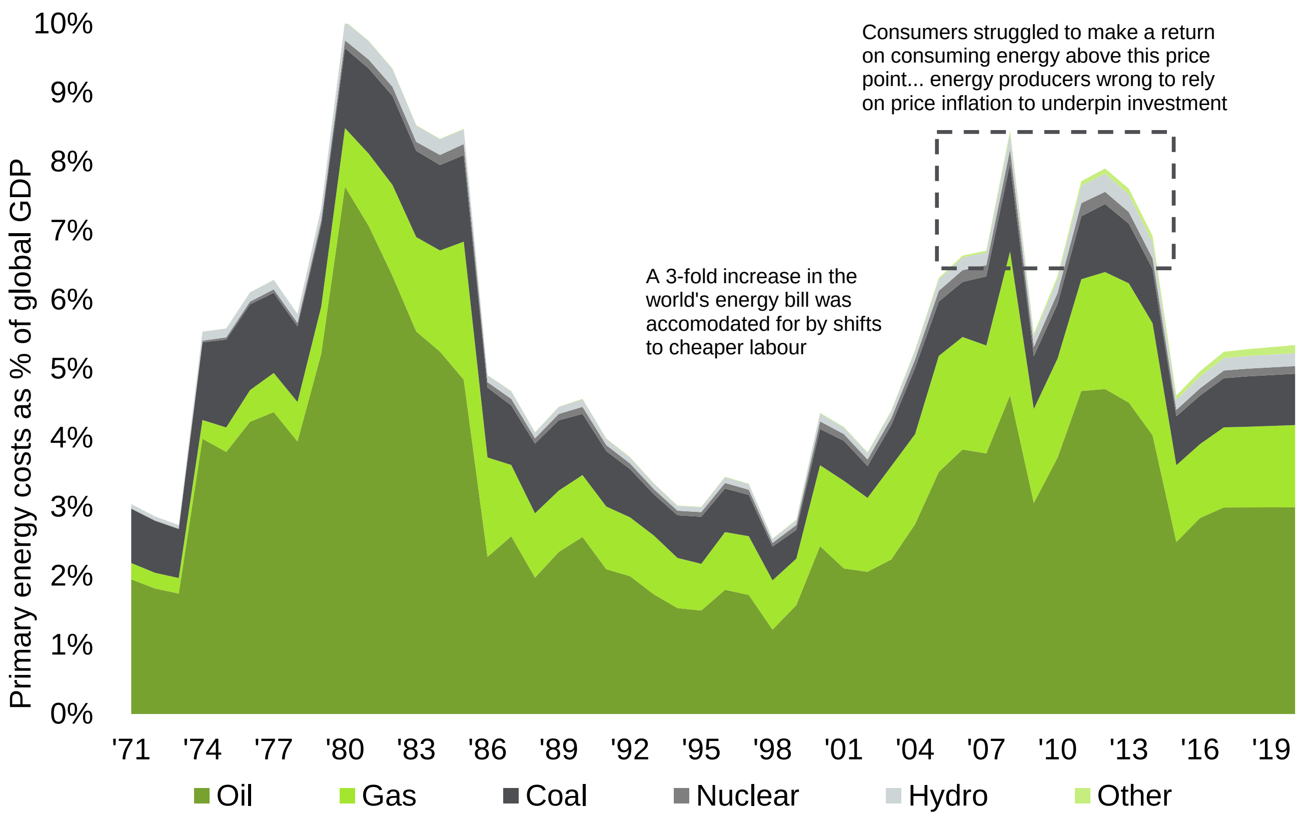
- The distribution of effects will depend on national energy intensity, stranded assets, and the importance of energy to a particular economy, in terms of GDP, stranded assets, balances of payments, and employment.

The Impact on Global GDP

Energy costs are inextricably linked to global GDP. Energy is an input into production, alongside capital, labor, technology and other materials. Restricting energy (either directly or by making it more expensive) is therefore a negative supply shock, which will generally make it harder to produce, thereby lowering GDP.

Accordingly it is useful to examine energy costs as a percentage of global GDP in a historic context, to be able to consider the likely future impacts of the higher initial spend on following a lower carbon path.

Figure 104. Energy Costs (Fuels) as a % of Global GDP



Source: Citi Research; BP Statistical Review of Energy

As Figure 104 shows, energy costs in terms of energy supply (rather than capex), have varied widely since 1970, between around 3% and 10% of global GDP. The oil shock of the 1970's is well known, as is the dampening effect that it had on global growth. In more recent years, increases in the cost of energy to 7-8% (a threefold increase in the world's fuel bill) have been offset by the shift to cheaper labor as well as savings made elsewhere.

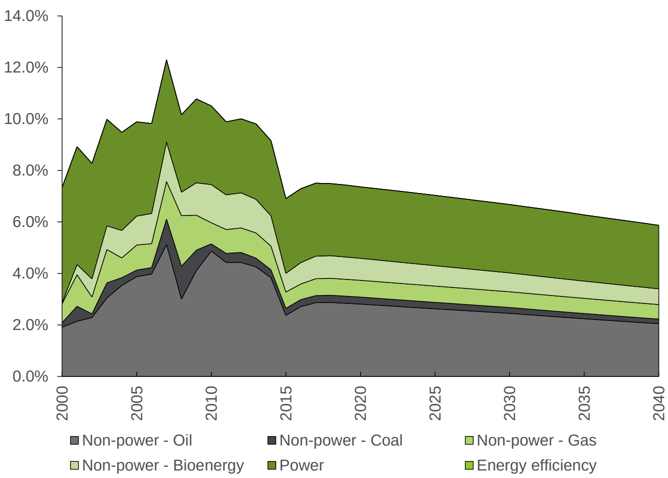
However, this approach only shows one part of the equation. Clearly if we shift towards an energy mix with a greater proportion of renewables such as our Citi 'Action' scenario, fuel costs will be reduced (solar and wind use no 'fuel'), but this relative reduction in fuel usage would be accompanied by a relative increase in the capital spend per MW (the capital cost of renewables is higher than conventional, albeit the LCOE may not be in future). In addition, as we saw earlier, a low carbon future in the Citi 'Action' scenario is likely to entail a significantly higher spend on energy efficiency than our 'Inaction' scenario.

Accordingly, we have adjusted these energy cost figures to incorporate the spend on power generation, using our LCOE approach examined in detail earlier. Since this inherently captures fuel costs where appropriate, we have adjusted the previous primary energy demand figures by removing the portion of demand used in power generation. The resulting spend on power, non-power and energy efficiency can be seen in Figure 105 and Figure 106. Future figures are calculated using current prices for commodities, with learning rates derived earlier continuing for renewables.

A lower carbon future could raise the issue of the tax that governments raise from the use of fossil fuels

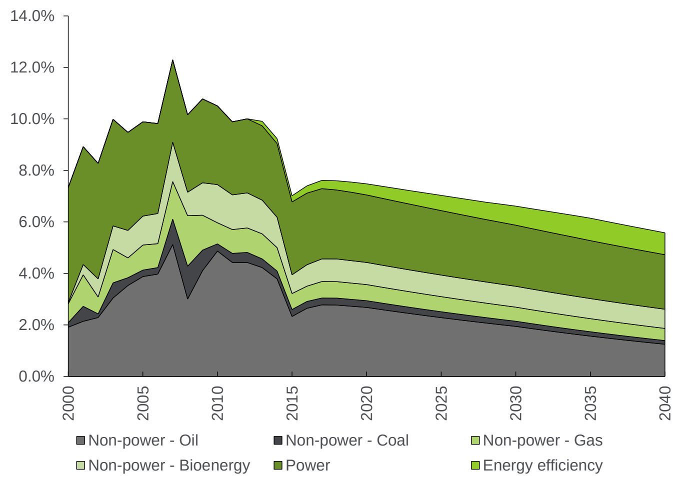
This more holistic approach of capital investment and fuel cost, while not perfect, effectively captures many other effects in the energy complex such as energy transport, upstream margins, refining/conversion and not least taxation. It also raises the issue of the tax that governments take from fossil fuels, on which a lower carbon future will clearly have a material impact. Offsetting that is the level of subsidies currently used in fossil fuels versus renewables, and put as a percentage of global GDP.

Figure 105. Primary Energy (ex-Power) and Power (LCOE) Spend Under Citi's 'Inaction' Scenario



Source: Citi Research

Figure 106. Primary Energy (ex-Power) and Power (LCOE) Spend Under Citi's 'Action' Scenario

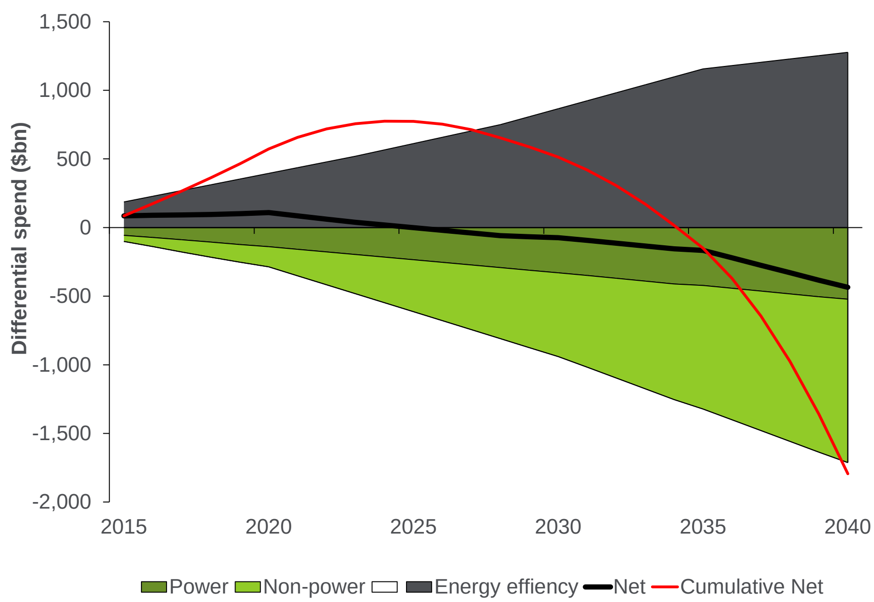


Source: Citi Research

As discussed in the earlier 'Action vs. Inaction' chapter, the totals of investment in both primary energy and power (capex and fuel) are actually remarkably similar from 2015-40 ($190.2trn and $192trn). With a difference of 'only' $1.8 trillion spread across 25 years, it is perhaps unsurprising that the charts look very similar.

Figure 107 helps to highlight the differences in spend. It shows the 'extra' spend on energy efficiency, with the corresponding lower spend on both power and non-power in both capex and fuel terms, with the annual net difference in spend, and the cumulative difference shown by the lines.

Figure 107. Net Differential Spend Between Citi's 'Action' and 'Inaction' Scenarios with Cumulative Total of Spend (Positive) or Saving (Negative)



Source: Citi Research

Of most interest are the 'difference' lines. As the 'net' line shows, in the earlier years we invest more in energy efficiency than the power and fuel savings, before we move to a net 'in-year' overall saving in 2025 and beyond. At this point the cumulative cost/saving line reaches its inflection point at a net cumulative extra spend of $775 billion, before the savings start to reduce this figure. The cumulative cost then becomes a cumulative benefit from 2035 onwards, and would increase significantly thereafter. Clearly discounting would have an effect on the net present value of costs and benefits, a topic that was discussed at length earlier in this report.

Returning to the spend as a percentage of GDP charts, it is also worthy of note that the total spend as a percentage of GDP (admittedly at current prices) remains significantly lower than the peaks seen in the early 2000's and in the 70's, effectively 'freeing up' room to spend the extra in capital costs on renewables and energy efficiency.

The effects of GDP of a lower carbon path are potentially very small – largest annual impact is only 0.1% of global GDP

The likely effects on GDP of following a lower carbon path are, in our opinion, potentially relatively small (though the mix of those effects could vary significantly). The effects on production will depend on the importance of energy to individual economies (in terms of energy intensity, as discussed earlier) and in terms of substitutability. Higher upfront costs will hurt supply in the short-term, while the benefits will be reaped later. However, the hit to growth tends not to be too severe except the cases of very big shocks. The basic rule of thumb is to calculate energy as a share of GDP, and multiply this by the change in 'price' (i.e. if energy is 5% of GDP and energy prices rise by 10%, the cost would be 0.5% of GDP). Accordingly, on the basis of our (undiscounted) figures, the largest annual impact would still only be just over 0.1% of global GDP, with a cumulative effect peaking at around 1% of current GDP. Once again, in the context of the costs to GDP from the impacts of climate change (0.9% to 2.5% of global GDP loss for a temperature increase of 2.5°C), this seems like a very small cost.

Clearly the cost of energy in future won't be as smooth as portrayed in the charts – there will be supply shocks which could potentially push costs up to or beyond that 10% threshold where GDP begins to be materially affected. However, a more diverse energy mix could potentially make those shocks less severe, or more manageable.

As discussed, the extent of any energy 'shock' depends on 1) on the importance of energy in production and 2) one's ability to substitute for it. This highlights several other dynamic elements with potentially positive connotations:

- On average energy use per production has come down. All other things being equal, including one's ability to substitute for energy, this means a shock to energy supply is now less painful than in the past (though for emerging markets with higher energy intensity the shock remains larger, especially for those industrializing currently).
- One's ability to substitute is usually a function of the time horizon. The reason previous spikes in oil prices were so painful (and hit GDP so hard) were that it is so painful to improvise in the short-term – e.g. engines are built for a certain type of fuel. That means that sudden, sharp shocks are very painful in terms of output (and a lack of substitutability in the short-term therefore means that price spikes will be large). Even a major shock that is anticipated should have smaller effects/consequences. Accordingly, the broader energy mix, alongside the lack of fuel elements for renewables could have a positive effect in reducing the impact of future energy shocks (at a global level, though again, national effects will vary).
- The world is currently facing signs of a persistent demand shortage (secular stagnation). Against that, adopting a lower carbon route which actually boosts demand currently (i.e. increased investment) could be an (admittedly small) positive for growth, in that it potentially avoids people being otherwise unemployed.
- Sometimes when you invest, the returns can dramatically exceed what you put in. If, as seems possible, energy savings allow us not only allow to achieve our climate targets, but make energy much, much cheaper in the long run, there might not be 'any' hit to growth, in fact the effect could be positive.

However, to achieve a lower carbon future will require longer term vision on the part of policymakers, and must overcome parochial thinking.

Who Pays?

Paying for climate change has two meanings; paying by restricting one's own emissions, and paying for mitigation elsewhere. Carbon markets, if they can be integrated to a greater extent can help to integrate these two approaches.

The problem of externalities plays a huge part in the discussion of who should pay

The key issue with who pays is that there are externalities; the fact that one country will not alone suffer the consequences, positive or negative, of its climate-affecting actions makes it more difficult to reach socially and globally optimal solutions. Hence international coordination and cooperation is required (but difficult to achieve). More specifically, the issues are as follows:

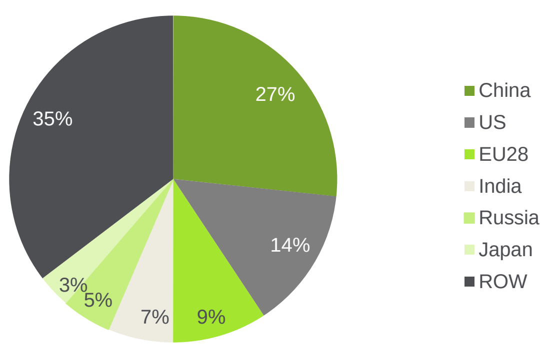
- The majority of future energy demand and emissions growth will come from emerging markets.

- The legacy issue that developed markets now have less energy-intensive economies, and hence restricting their carbon output would be less expensive in terms of GDP impact, combined with the fact that developed markets have historically accounted for the bulk of carbon emissions which have created the climate problem in the first place.

Developed markets do acknowledge the legacy argument, and most appear willing to play their part – the $100 billion climate fund pledge is a good example. However, it is the extent to which they are willing to act, and in particular sensitivity over the relative size of contributions, which are key issues.

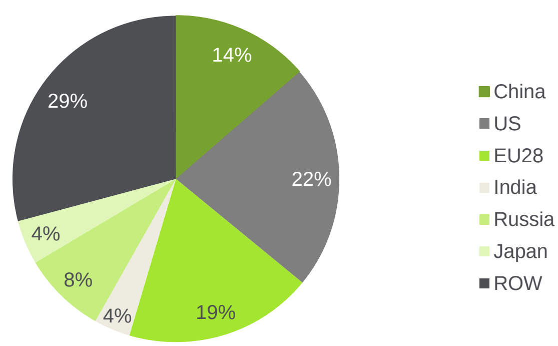
The view that developed markets are doing their part by spending more per MW on new generation capacity in the form of renewables, and that emerging markets will be responsible for the future growth in emissions and hence should pay is in our view too simplistic. It ignores the fact that the existing levels of carbon in the atmosphere were put there by the developed world in becoming 'developed' – i.e. they used the same cheap and dirty power to get richer in previous decades, and hence to adopt a holier than thou attitude to emerging markets is disingenuous. Indeed there is an argument that developed markets are responsible for more than their share of the residual carbon in the atmosphere, given that emerging markets are at least attempting to go for a balanced and less emitting energy complex than developed markets did historically. To which developed markets would probably reply, "But we didn't know at the time, but now you do."

Figure 108. % of Annual CO_2 Emissions by Country



Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Figure 109. % of Cumulative CO_2 Emissions by Country



Source: Boden et al. (2013), Houghton et al. (2012), Citi Research

Moreover, expecting emerging markets to spend more on power per unit than they simplistically need to could potentially slow their development, which could effectively keep millions of people in technical poverty for longer than is necessary.

Given the joint responsibility for historic and future emissions, it would seem logical that everyone should pay their fair share, especially since we all suffer the consequences of inaction. It would be theoretically possible to create attribution formulae based on cumulative emissions relative to cumulative GDP (potentially on a per capita basis) to enable a fair allocation of costs and an equitable funding mechanism, though once again this falls foul of the argument that emerging markets are manufacturing goods for which developed markets are providing the demand. Mechanisms and political solutions are not however the purpose of this report (instead it being focused on investment). The INDC's to be submitted before COP21 should at least form a starting point for discussions from which some countries can be pushed to act further.

The Distribution of Effects

The key issues regarding the distribution of effects are as follows:

- Emerging markets show significantly higher levels of energy intensity, and are responsible for the vast majority of the growth in energy demand, and hence the impact of the higher cost of energy is likely to impact them disproportionately.
- Whether countries are energy importers or exporters, of which fuels, and how important that energy industry is to their economy will be of key importance to the effects on localized GDP.
- The geographic distribution of energy reserves around the world will affect countries in terms of their 'assets' and future ability to develop and benefit from these reserves (both in terms of fossil fuel reserves, as well as renewables resources such as insolation levels, i.e. how sunny the country is)
- Collectively these will have an effect on local levels of employment.

Making it Happen: Funding a Low Carbon Future

Highlights

- Directing the vast amounts of capital required to transform our energy mix will require innovation on the part of financial markets and the instruments therein.
- While green investment has ballooned in recent years, it is still tiny compared to what will need to be invested, and as a portion of both equity and debt markets. We see the most scope in the credit markets, given that renewable energy and energy efficiency investments lend themselves well to debt financing given their stable cashflows and operating predictability.
- The potential yields generated offer enormous attractions to investors against a backdrop of historically low global interest rates, if politicians, regulators and policy makers can overcome the barriers holding back private capital, outlined below.
- The limited investment to date is not due to a lack of investor appetite; there is an increasingly large investor base with tens of trillions of dollars of assets under management that wishes to gain exposure to 'green' investments.
- With both the need and the desire to invest, the missing link has up to now been lack of availability of investment vehicles of sufficient quality, i.e. investment grade.
- The majority of energy investment will be required in emerging markets, where financial markets are typically smaller, less stable and liquid, and political, FX etc. risks are perceived as higher. Historic finance here has been provided by Development Finance Institutions (DFI's), who are now effectively 'maxed out'.
- The key barrier to attracting sizeable debt investment into energy in emerging markets has been the lack of investment grade vehicles available. If DFI's or other supranational organizations are able to offer some form of credit/risk enhancement to raise emerging market credit to investment grade this could bridge the gap between the need for capital and the desire to gain exposure
- In developed markets the majority of investment will be in energy efficiency which presents its own issues, given the lack of cashflows which can be ring-fenced to cover financing costs.
- Securitization offers enormous potential for both energy and efficiency investment, though banking and insurance regulations such as Solvency II actively discourage entities such as insurance companies from investing in securitized assets.
- We examine new vehicles such as securitized energy efficiency fixed interest instruments, and the emergence of green bonds and yieldco's, all of which offer enormous potential for the future.
- We also highlight the possibilities offered by R&D in terms of the potential it offers to reduce the overall cost of transitioning to a low carbon energy mix.

Introduction

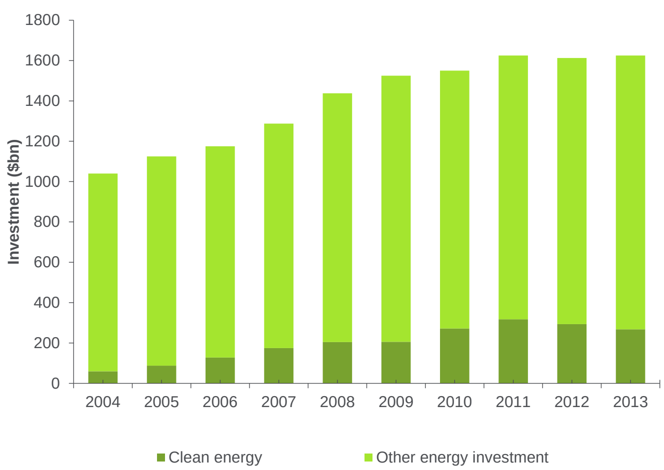
As the previous chapters have highlighted, an enormous amount needs to be invested in energy and efficiency over the coming 25 years, some $50 trillion in capex alone, or close to $200 trillion if we include the cost of fuel. However, as we have also seen, the sums of money required to go down a low carbon path while larger, are in context not that different, especially when we consider the potential costs of inaction. Moreover, the capital element of that investment could actually act as a boost to global growth (or at least not too much of a brake). However, that investment will be in different locations and different industries than might otherwise have been the case. Accordingly it is not just global political will that has to come together to tackle the issue of potential climate change; to redirect investment of that magnitude into new areas will require innovation in both financial markets and the instruments therein.

Historic Investment Levels

In 2014, investment in renewable energy surpassed that of conventional power generation, totally around $250 billion per annum

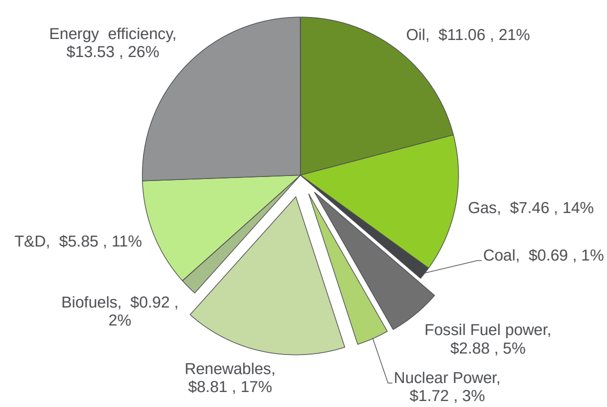
While the world of green investment has ballooned over the last 10 years, it is still a drop in the ocean compared to total energy investment, and to the amounts required to adopt a low carbon future. Nevertheless it is worth noting that in 2014 we expect investment in renewable energy actually to have surpassed that of conventional power generation; in capacity terms it was almost equal in 2013 - a milestone that few would have thought possible a few years ago, and one that offers faith in our ability to change our investment behavior relatively rapidly.

Figure 110. Investment in Clean Energy in the Context of Total Primary Energy Investment



Source: Citi Research, Bloomberg New Energy Finance, IEA

Figure 111. Cumulative Investment 2014-35 by Type Under the IEA's '450 Scenario'



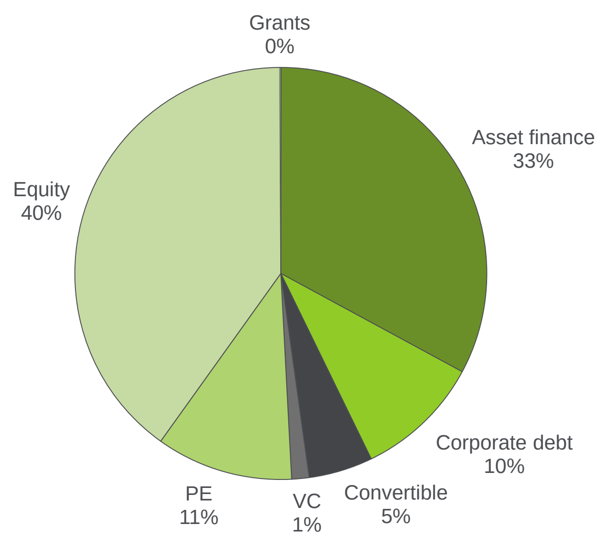
Source: IEA (2014)

Figure 110 shows investment in clean energy has been around $250 billion per year in recent years, rising further to $310 billion in 2014, but is still dwarfed by the total investment in primary energy (a total of around $1.6 trillion per year). Onto this figure we should really add the estimated current expenditure in energy efficiency of $160 billion per year to gain a full picture of 'cleantech' and energy spend. Thus renewables represents around 17% of current total investment in primary energy (as opposed to just power).

However, as Figure 111 shows, the cumulative investment figures out to 2035 under the IEA's '450 scenario' are enormous. Energy efficiency and renewables are estimated by the IEA to require capital investment of $13.5 trillion and $8.8 trillion over the next two decades. Interestingly renewables stays at around 17% of that total investment, with an annual spend which is actually only at 2014 levels, and hence markets are already arguably providing enough capital to the renewables industry (in quantum at least, if not necessarily in the markets where it will be needed). The biggest change is the enormous increase in investment in energy efficiency which rises from current levels of around $150 billion per year (depending on definitions) to over $500 million per year, being largely responsible for the increase in annual spend on energy and efficiency to around $2.5 billion per annum from 2030 onwards.

So far the bulk of the investment into clean energy has been equity and project finance, a situation that continued in 2014, as shown in Figure 112.

Figure 112. Announced Investments Into Clean Energy and Efficiency by Financial Vehicle, 2014



Source: Citi Research, Bloomberg New Energy Finance

As the pie chart shows, equity in its various forms still provided around 50% of finance flows into the space in 2014, with the majority of the remainder being covered by asset finance, with bonds and convertibles making up just 15%.

If we take this equity investment in the context of the global equity market capitalization of $70 trillion, it pales in significance. Even more extreme is to compare the fixed income part of annual investment (effectively around $100 billion) against global credit market values of $166 trillion, equivalent to just 0.06%.

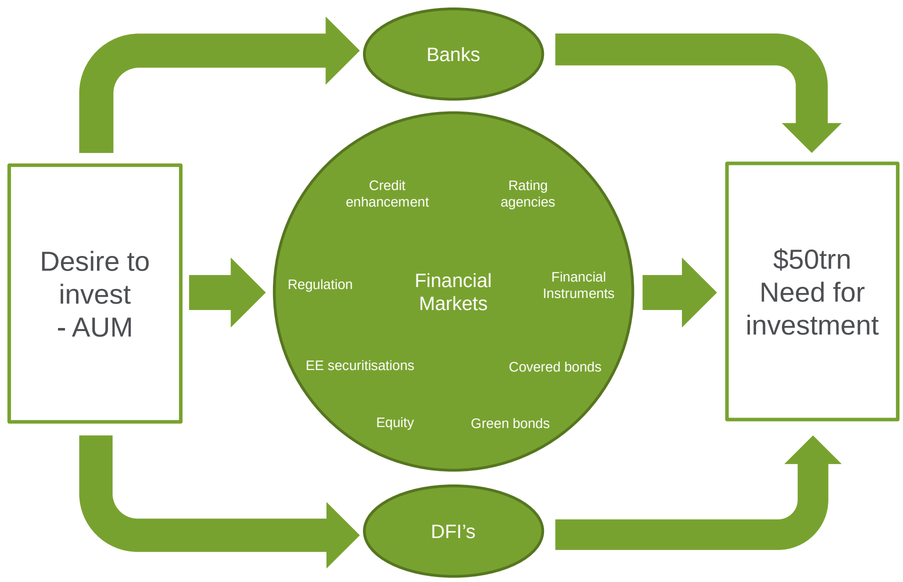
It is therefore only a very small part of the overall investment market which is in any way directly exposed to the low carbon theme. Given the topic's significance and broader implications for markets in terms of its potential impacts on global GDP, health, population displacement, agriculture/food, sea levels, not forgetting the enormous cost of transitioning to a lower carbon energy model, that seems a remarkably small percentage.

Institutional investors are investing more in clean energy fuels

Yet this lack of exposure is not due to a lack of appetite; The IIGCC (Institutional Investors Group on Climate Change) has more than 100 members representing $12 trillion in assets under management; The Carbon Disclosure Project works with institutional investors with $95 trillion of asset under management (AUM); The Climate Bonds Initiative works with institutions with $34 trillion AUM. As discussed earlier, the Norwegian Government Pension Fund (the world's largest sovereign wealth fund) has announced that it will no longer invest in companies that are overly exposed to coal, and numerous other institutions have undertaken similar approaches to make their portfolios more environmentally friendly.

So, if the investment is needed, there are project developers seeking capital, and the appetite and interest in gaining exposure (or limiting exposure to carbon intensive investment) is there from a very large part of the institutional investor base, why isn't the investment already happening? The simple answer is the limited quantity and quality of the investment vehicles available.

Figure 113. While DFI's and Banks have Historically Provided Much of Financing, Capital Markets Must Now Innovate to Facilitate Investment



Source: Citi Research

Therefore, this investment needs to be facilitated via the creation or adaptation of new financial instruments, and developing sizeable, established, liquid and stable markets for these products.

The debt market has the largest potential

While equity markets have mobilized themselves, it is the debt market where perhaps the greatest potential lies. Renewable energy projects lend themselves very well to debt capital markets; they have very little operating variability, and have long term stable cashflows which can therefore take relatively high levels of leverage (in some cases up to 80%) thereby minimizing the cost of capital and keeping investment costs as low as possible for a given return. The key risk on many of these projects is regulatory/political rather than operational – if this investment program is to happen, it must be against a stable regulatory backdrop with, most importantly, an end to the retrospective regulation that has been seen recently in various areas around the world. This perceived risk ultimately pushes up costs and discourages investment, the opposite result to that which is desired.

The returns offered by these projects and their long term nature should offer significant attractions against the backdrop of historically low global interest rates, and a worldwide search for yield. As discussed, the longer term (20 year) nature of many of these projects would allow pools of investors such as pension funds, insurance companies etc. to match long-term liabilities with long-lived assets.

The challenges of allowing the investment to flow are very different for clean energy investment versus those for energy efficiency; we examine these in turn below.

Financing Renewable Energy Investment

While developed markets need to invest in energy efficiency rather than new capacity, growth in energy demand is coming from emerging markets meaning that it is here that the bulk of asset finance will be required. The equity and certainly debt markets in these regions are unlikely to be large, stable and liquid, and hence potentially unsuited to financing these investments, or at least not with a low cost of capital. This creates another financial hurdle, especially when these projects must compete in LCOE terms with often sizeable subsidies on fossil fuels. In emerging markets, much of the financing therefore currently comes from banks, on whom current pressure to reduce the scale and risk of their balance sheets creates another headwind.

Most investment in these sectors in emerging markets has hitherto been funded by DFI's. However, these institutions now largely find themselves at capacity, a situation exacerbated by regulatory constraints placing pressure on banks to reduce leverage or raise the quality of their debt portfolios.

While private capital has been actively engaged in investment in renewables and infrastructure generally in OECD markets, there has as yet been little involvement in the typically sub-BBB emerging markets, due to the inherent macro-economic, political, foreign exchange, refinancing, governance and regulatory risk. Yet with DFI's effectively 'maxed-out', and in the absence of an injection of fresh capital, private capital must be enticed into these emerging markets to co-invest alongside the DFI's.

The search for yield against a backdrop of historically low global interest rates offers enormous potential, if politicians, regulators and policy makers can overcome the barriers holding back private capital from investing in this sizeable opportunity.

In our opinion, the credit rating issue is one of the most significant issues to be addressed; if DFI's or other supranational organizations are able offer some form of credit/risk enhancement to raise emerging market credit to investment grade this could bridge the gap between the need for capital and the desire to gain exposure, and address the enormous emerging market infrastructure deficit which exists, and not just in the world of energy. Indeed, vehicles such as the $100 billion green investment fund might ultimately facilitate much greater levels of investment if used for credit enhancement rather than by investing directly.

Clearly securitization offers enormous potential in these markets. However, even if DFI's can successfully bridge the gap to investment grade, banking and insurance regulations such as Solvency II actively discourage entities such as insurance companies from investing in securitized assets.

Projects certified under the CDM saved 2.9 billion tonnes of CO_2 equivalent between 2008 and 2012

If these emerging markets can be opened successfully, then mechanisms such as the Clean Development Mechanism (CDM) or Joint implementation (JI) discussed earlier could be refined to further facilitate cross-investment between countries. The main issue with carbon markets and hence these mechanisms, is grandfathering and abuse via local over-issuance of permits which force a (potentially unfair) flow of capital from one country to another. The UNFCCC estimates that projects certified under the CDM saved 2.9 billion tonnes of CO_2 equivalent between 2008 and 2012 – in the context of annual emissions of 40GT this is relatively small, but with the right political will, it could become a much larger driver.

An example of these innovative new financing mechanisms is the World Bank's Pilot Auction Facility (PAF) for methane and climate mitigation. This is a 'pay for performance' mechanism, which uses auctions to allocate funds into projects in emerging markets that reduce methane emissions. Bondholders in a project will be issued with emissions reductions certificates, tradable via the CDM, once emissions have been verified (hence the 'pay for performance'). What is innovative is that the PAF entails a put option at a pre-agreed strike price, effectively guaranteeing a minimum price for the CER's. If carbon prices fall, the bond holder is protected, but if carbon prices are stable/rise, the bondholder keeps the benefit. The PAF effectively facilitates lower-risk investment into EM methane reduction projects, at no upfront cost to the World Bank (unless carbon prices fall, in which case it would be liable for the different between the strike price and the market carbon price).

Financing Energy Efficiency Investment

In developed markets the 'extra' investment of following a low carbon path is forecast to be mainly in energy efficiency, which presents its own difficulties. Energy efficiency investment is unintuitive; while normally one invests in an asset which generates cash returns, in the case of efficiency the return usually comes via future avoided costs (i.e. lower energy bills/usage). It's effectively the same thing, but it makes financing it harder as the investment is unsecured, and doesn't explicitly generate a cashflow which can be ring-fenced to cover for example interest payments on the investment cost. Energy efficiency creates greater net cashflows to an entity, an element of which therefore have to be earmarked to cover the interest on investment. This lack of ring-fencing is a significant hurdle. In addition, if energy prices fall via reduced demand (from greater efficiency), the 'return' on energy efficiency investment falls as the relative benefit is squeezed.

Given the difficulty in financing energy efficiency, the majority of investment to date has been funded from corporate or personal/household cash reserves, but the right financing mechanisms could once again accelerate and grow investment.

The key issues in energy efficiency investment are size, standardization, accreditation, and the lack of pipeline generated from existing public subsidies which are limited both geographically and in scale.

Given that much of the necessary investment in energy efficiency will be undertaken by households, the individual project size will be very small (typically $7.5-$10K per household project in the US) across a fragmented range of property types. This will therefore require different forms of finance, and pooled or securitized investments are likely to be necessary. Innovative financing solutions in solar in the US where panels are installed on household roofs, but paid for by a third party, the return being shared, shows how goals can be achieved at a residential level without expecting the householder to put up the full capital investment. Other examples are PACE (Property Assessed Clean Energy) loans which can again be securitized. Avenues such as On Bill Repayment (OBR) offer forms of enhancing credit quality via the use of another entity's revenue collection mechanism.

WHEEL aims to create a national financing platform that can help home owners make necessary improvements such as insulation

Citi and Renew Financial recently announced the first ever asset-backed security (ABS) transaction comprising unsecured consumer energy efficiency loans, the first securitization from the WareHouse for Energy Efficiency Loans (WHEEL). Announced in 2014, WHEEL is an innovative public-private partnership between national leaders in finance and energy in the US, including Citi, Renew Financial, Pennsylvania Treasury, the National Association of State Energy Officials, Energy Programs Consortium and a growing number of states and utilities. Its aim is to create a national financing platform to bring low-cost, large-scale capital to government and utility-sponsored residential energy efficiency loan programs. Through the recent ABS program, homeowners can borrow up to $20,000 at very competitive rates to make a range of improvements to their homes, such as HVAC equipment, water heaters, roofing, insulation, windows and energy efficient appliances. While a relatively small pilot scheme at the moment in 3 states (Pennsylvania, Kentucky and the Greater Cincinnati Energy Alliance have all joined WHEEL), numerous additional states are expected to join soon, and the model should be highly scalable. These mechanisms are not grants, but rather a 'socialized credit enhancement facility', which provides cheaper capital for energy efficiency projects to those who might otherwise be unable to gain access.

Perhaps greater potential for debt capital markets comes via spending on public buildings in terms of energy efficiency. Given very high levels of real estate ownership of building stock by local councils and authorities, the scope for sizeable investment volumes funded by municipal borrowing ('green munis') is significant. Several examples of this already exist, for example the Delaware Sustainable Energy Utility, where an energy efficiency revenue bond of $67.4 million resulted in net cashflow savings for government agencies in the state equal to 30% of aggregate project cost.

Even if states are unable to issue green bonds themselves, there is still scope to achieve energy efficiency investment and savings; Detroit recently replaced all of its street lighting with energy efficient lighting, achieving significant savings on its energy bills in the process. The notable fact here was that this was facilitated via a loan from Citi to Detroit which was then refinanced, effectively creating an investment grade vehicle from a municipality with a fairly low rating. ‘Green investment’ is also likely to be well received by voters generally; given that it achieves financial and energy savings as well, the attractions are likely to be significant, demonstrating the potential scalability of municipal green bonds.

The above represent examples of projects in which Citi has been involved, as part of its goal to lend, invest and facilitate $100 billion within 10 years to finance activities that reduce the impact of climate change. This new target, announced in 2014, follows Citi's previous commitment to facilitate investment of $50 billion over 10 years, which was completed 3 years ahead of schedule in 2014.

A large part of energy efficiency savings will also be in the transport sector, and here again much of the investment will be taken by corporates who could effective issue green bonds (we have now seen the issue of green corporate bonds by several large multinationals such as Toyota) to finance these investments. Grants could also have an effect here, as has been seen with grants to purchasers of some electric vehicles, thereby offsetting the increased capital cost.

Storage while not technically reducing overall consumption, offers the potential for more efficient power markets, smoothed demand profiles and less stranded generation assets. As such it can potentially reduce the overall cost of an electricity market, thereby freeing up capital for investment elsewhere. Residential storage in combination with home energy management systems (such as Hive and Nest) also offers reduced consumption and cost. (See Battery Storage: The next solar boom?)

Regulatory Considerations

Efficiency standards could also make a difference to the overall energy usage

It is not just financial markets that have their part to play. From a regulatory perspective, greater application of efficiency standards, knowledge, and accreditation will also facilitate greater investment in energy efficiency. Efficiency standards and understanding/marketing thereof on electrical appliances, cars and buildings will also help to reduce overall energy usage.

One thing we have learnt from regulation is that it needs to be regularly updated and flexible enough to adapt to externalities such as lower economic activity, the main reason that an effective over-issuance of permits relative to lower economic activity has left carbon prices so low in the EU ETS. The same was true of solar regulation in Germany; a lack of flexibility in granting high legacy feed-in tariffs to solar farms despite a massive fall in the price of solar panels led to super-normal returns and an unjustifiable subsidy bill which inevitably led to a boom and bust cycle. Conversely what must be sacrosanct is that regulation must not be retrospective, as witnessed in several countries, most notably Spain. This raises future costs of capital for everyone (and not just in that region) and deters future investment.

Ending fossil fuel subsidies and diverting those funds into cleaner energy could have an effect on the mix of energy sources at a limited cost

A particularly tricky area will be an end to end to fossil fuel subsidies (and potentially renewable subsidies). Subsidies are incredibly negative for both energy efficiency and renewables in that they make the relative merits of undertaking a project much less compelling. The justification for subsidies is that energy is necessary to boost growth and in developing markets energy needs therefore to be available and affordable. However, diverting those subsidies into different forms of energy (cleaner energy, e.g. gas vs. coal, or renewables, or indeed energy efficiency) could have a transformational effect on the energy complex at relatively limited cost. The IEA estimated that fossil fuel subsidies in 2013 amounted to $548 billion. Admittedly the implied subsidy will fall significantly this year, potentially to we estimate $300-350 billion given the recent fall in the oil price, but in the context of total primary energy spend of $1.6 trillion per year, this is still a very large figure. Add to this the estimated $121 billion of global renewable subsidies in 2013 (IEA), and the extent to which the world is already manipulating energy markets becomes clear; the challenge therefore is simply to adjust them in a different direction.

Figure 114. Fossil Fuel and Renewable Energy Subsidies as a Percentage of Total Global Energy Spend

Source: Citi Research, IEA

Financial Instruments

We examine below some of the key instruments available which could be developed further to facilitate low carbon investment:

- Green bonds
- Yieldco's
- Covered bonds
- Securitization

Green Bonds

Recent years have seen the emergence of the so-called 'green bond'.

Green Bonds are a fixed income instrument, the proceeds of which will be used exclusively to finance 'Green Projects', defined as any activity or project which promotes progress on environmentally sustainable activities, and is in accordance with the recently launched 'green bond principles' outlined below:

1. **Use of Proceeds**: The finance raised by the green bond must be used for environmentally friendly and sustainable projects such as renewable energy, energy efficiency, sustainable waste management, sustainable land use, biodiversity conservation, clean transportation, sustainable water management, and climate change adaptation.

2. **Project Evaluation and Selection**: The green bond issuer must outline the decision making process it intends to adopt in determining the eligibility of projects to receive proceeds, in terms of which specific category of project, the criteria which makes the project eligible, and the environmental sustainability objectives.

3. **Management of Proceeds**: The proceeds should be credited to a sub account and tracked as they are invested with a high level of transparency. The use of an auditor or other third party to verify allocation of funds and tracking is encouraged.

4. **Reporting**: Issuers should report at least annually on the use of proceeds, in terms of which projects have been financed. The principles also recommend the use and disclosure of qualitative and quantitative performance indicators of the expected environmental sustainability impact of the investments

Types of Green Bonds

There are four main types of Green Bonds: The most popular and mainstream is a regular fixed income bond which has a full guarantee by the Issuer, however the "use of proceeds" of the bond can only be used for "climate friendly" projects, as mentioned above.

- **Green Use of Proceeds Bond**: the most common type, a normal fixed income bond with recourse to the issuer, the proceeds of which must be used for environmentally friendly/sustainable projects.

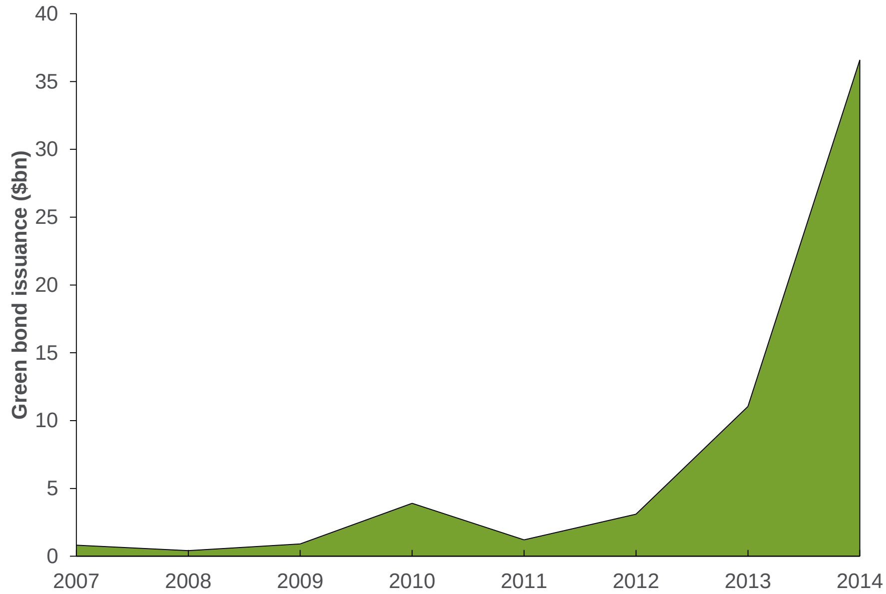
- **Green Use of Proceeds Revenue Bond**: (non-recourse to issuer, linked instead to income streams).

- **Green Project Bond**: Linked to a single/multiple qualifying green project, with no recourse to the issuer.

- **Green Securitized Bond**: A bond with collateral and cashflows provided by multiple projects.

The majority of green bonds issued to date have been via supranational organizations such as the World Bank and International Finance Center (IFC), though the last couple of years have seen corporate green bonds emerge such as those from Unilever and Toyota. Figure 115 highlights the rapid growth that has been seen in the green bond market.

Figure 115. Historic Green Bond Issuance



Source: Climate Bonds Initiative

In 2014 green bonds issuance totaled $37 trillion

As Figure 115 shows, green bond issuance rocketed in 2014 to nearly $37 billion, and expectations for 2015 vary from $50 billion to $100 billion, showing further rapid growth. Cumulative green bond issuance currently stands at $59 billion via some 300 bonds from 19 countries in 23 currencies.

The markets for green bonds are still evolving, but the emergence of accrediting organizations and industry guidelines/best practices such as the green bond principles is helping to develop the market.

Yieldco's

Recent years have seen the birth of the yieldco in both the US and more recently Europe. A yieldco is essentially an investment vehicle which invests in multiple projects, thereby once again reducing risk vs. single asset project finance via the portfolio effect. These projects are typically levered at anything up to 80%, with the long term stable cashflows being well-suited to cover interest payments on the debt and to provide dividends to equity investors. Dividends paid are typically 90% of cash available for distribution (CAFD), thereby providing a dividend buffer to cover limited volatility in cashflows, as well as providing cash to invest in new projects which are typically dropped down from a sponsor/parent via a right of first offer (ROFO) agreement. As well as providing spread-risk equity investments, yieldco's can raise debt at a parent rather than project level thereby once again reducing single asset risk.

Investors tend to view these vehicles on a total return basis, i.e. dividend yield plus CAGR of dividends, with a currently tight valuation correlation. However, it is notable that companies in areas where regulatory risk is perceived to be higher (particularly where there is a history of retrospective regulation), yields need to be higher to offset this perceived risk. This starkly demonstrates the impact of a lack of regulatory stability or trust on the implied cost of capital, with knock on effects on the relative costs of different energy forms and the ability of nations therefore to transform their mix.

Covered Bonds

One of the most promising 'new' instruments with the potential to fund green investment is the covered bond. A covered bond essentially has the advantage of not just being asset backed, but also benefitting from a guarantee from the issuer or another body such as a government or supra-national organization. This concept of dual recourse thereby reduces risk and leads to potentially higher credit ratings.

Covered bonds have been in existence for around 250 years, often being used in the real estate market, as well as in areas such as public housing. The similarities with green investment which also provides a 'social good' are obvious and could be used as a justification for guarantees from governments or other organizations.

Against a backdrop of banks trying to reduce leverage ratios these assets have the potential to be treated as high quality assets, thereby potentially allowing investment by banks without negatively affecting credit or liquidity thresholds.

Project bonds often entail construction risk, and guarantees could help to significantly reduce this risk and hence the cost of finance and overall project cost. This effect has already been witnessed in the US alternative energy sector with government loan guarantees during the construction of projects.

The other advantage of government guarantees would be that it would effectively give governments 'skin in the game'; given investors' perception that one of the largest single risks for many of the projects is regulatory, making the government a stakeholder would give greater comfort in the stability of regulation.

While governments have historically facilitated investment in alternative energy via feed-in tariffs, and investment or production tax credits to improve the relative economics of new forms of generation, as the LCOE's of these technologies improve, these mechanisms become less necessary. Accordingly, the capital freed up by the removal of these subsidies could be used to provide guarantees for certain types of investment.

Other Financial Instruments

While equity and evolving fixed income instruments will provide the bulk of the financing for the energy transition, there are other financial instruments and markets that will be no less important. The insurance industry has long been interested in the potential effects of climate change given the associated liabilities. Instruments have existed for decades to allow investors to effectively hedge weather risk – for example temperature (degree-days) based instruments in the gas/utilities sector offsetting demand volatility. However, instruments which provide insurance against wind volatility are also being developed, and could once again reduce risk and volatility in this and other green sectors, thereby improving credit quality.

Research and Development

The Global Apollo Programme advocates greater investment in R&D that could promote a faster transition into cleaner energy

While not strictly a financial instrument, another mechanism which could help to promote the energy transition is incentives to allow R&D investment into new technologies. Current R&D budgets into green projects, climate change and geoengineering are currently estimated at just $5.9 billion per year globally (Global Apollo Programme). As we have seen, this figure is dwarfed by historic levels of combined subsidies into both alternative and conventional energy of well over $500 billion. By facilitating greater investment in R&D, the cost of existing solutions could be reduced more rapidly, as well as increasing the chances of the emergence of new technologies (such as CCS) which could have a material impact on the cost and speed of the energy transition, as well as offering the potential for 'game-changing' discoveries.

The Global Apollo Programme, a group consisting of some of the world's leading industrial, political and scientific minds, advocates exactly this, believing that a significantly larger investment into R&D could promote much faster and cheaper transformation of the energy mix. The group's ultimate goal is that via a major R&D program using the best resources available globally, baseload wind and/or solar should become less costly than coal-based power, in every country.

The Green Climate Fund

One positive to come out of the (otherwise disappointing) Copenhagen COP meeting was the agreement to create by 2020 a $100 billion per year green climate fund, the idea of which was that funding provided by developed nations would be used to help fund the transition to a cleaner energy mix in developing nations.

While this has received relatively downbeat estimates of its likely effectiveness, we should not ignore its potential impact, given the relatively limited differential in costs (which are becoming ever smaller) between clean and conventional energy. In context that $100 billion could fund much of the differential in spend in early years, and help to promote energy efficiency.

The downside is that as yet, only $10.2bn of those funds have actually been mobilized. Moreover, the efficacy of an entity such as this will be crucial; it must not become bogged down in bureaucracy and politics, which given its very nature will be quite a challenge.

Conclusions

The UN COP21 meeting being held this December represents the first real opportunity to reach a global legally binding agreement for the reduction of greenhouse gas emissions. Other past meetings have failed to achieve this; however, this time it feels different — countries including all the big emitters seem to be coming to the table with positively aligned intentions, against a backdrop of an improving global economy, and with public opinion broadly supportive. At the time of writing, a total of 21 countries and 1 region, including the US, China and the EU have submitted their national pledges (INDCs) to reduce GHG emissions over time. Nevertheless, to achieve this accord will take brave, forward-looking and non-partisan decisions on the part of policymakers.

The sums of money at stake in terms of investment in the energy sector are staggering — we estimate at $190.2 and $192.0 trillion between 2015 and 2040 for Citi's 'Action' and 'Inaction' scenarios, respectively. The difference is marginal between the two scenarios; mainly due to the fact that although we spend more on renewable resources and energy efficiency in the 'Action' scenario, this is offset by savings in fossil fuels through lower usage and the lack of fuels used by wind and solar. However, going down the route of 'Inaction' would lead to a reduction in global GDP which could reach $72 trillion by 2060 depending on temperature increase, scenario and discount rate used. We calculate the implied return of incremental avoided costs on annual spend and even though the returns are not spectacular, in today's context of low yields, and certainly in the context of potential implications of climate change inaction on society and global GDP, and with the additional benefit of cleaner air, the 'why would you not' argument comes to the fore, an argument that becomes progressively harder to ignore over time.

Yet adopting this low carbon future will not be without pain for some. Switching to a low carbon energy future would mean that potentially significant quantities of fossil fuels that would otherwise have been burnt would remain in the ground. This concept known as stranded assets or unburnable carbon has recently come to the forefront of the discussion on climate change. Investors are becoming increasingly concerned with this issue, and have increased their engagement with fossil fuel companies to understand the potential risks to their investments. A study has shown that if we are serious about meeting the 'carbon budget' and have a chance of limiting temperature increase to 2°C, then globally one-third of oil reserves, half of gas reserves and 80% of coal reserves would have to remain in the ground; we estimate that the total value of stranded assets could be over $100 trillion based on current market prices. However, Citi research shows that some conventional resources are already effectively stranded from an economic point of view due to low commodity prices, whilst coal companies are already experiencing some considerable stress as can be seen from the dramatic fall in seaborne thermal coal prices.

It is not just policymakers that must think outside of the box; to provide the vast amounts of capital required in different and new industries and locations will require significant innovation on the part of financial markets and institutions. Much of the energy investment behavior that needs to be changed will be in emerging markets given their demand growth, and energy and carbon intensity, yet financial markets in these regions are often less sizeable, stable and liquid. There is enormous investor demand for low carbon investment, with investor groups representing tens of trillions of dollars under management committed to investing in a more environmentally friendly manner. The stumbling block to date has been the lack of, and in particular the quality of many of the investment opportunities available. Bridging the gap between investors and the need for investment will be key in facilitating our energy transformation. We believe that the credit markets offer perhaps the greatest scope to facilitate this investment, and we highlight the significant innovation which is taking place currently, which while in its infancy offers significant encouragement for the future, as well as potentially exciting and very large opportunities for the financial world.

Paris offers a generational opportunity; one that we believe should be firmly grasped with both hands.

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Tim Kruger is the James Martin Fellow in the Oxford Geoengineering Programme at the Oxford Martin School, University of Oxford. Tim Kruger leads a group across the University of Oxford exploring proposed geoengineering techniques and the governance mechanisms required to ensure that any research in this field is undertaken in a responsible way. He has investigated in detail one potential geoengineering technique, that of adding alkalinity to the ocean as a way of enhancing its capacity to act as a carbon sink and to counteract the effects of ocean acidification. He is a co-author of the Oxford Principles, a set of draft principles for the conduct of geoengineering research which have been adopted as policy by the UK government.

Professor Cameron Hepburn is the Director of the Economics of Sustainability Programme at the Institute for New Economic Thinking at the Oxford Martin School and a Fellow at New College, University of Oxford. He is an expert in environmental, resource and energy economics. He has degrees in law and engineering, a doctorate in economics, and over 30 peer-reviewed publications in economics, public policy, law, engineering, philosophy, and biology.

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Cameron began his business career with work at oil multinational Shell, law firm Mallesons and then management consultancy McKinsey & Co. Cameron is now a founder-investor in the social enterprise and clean energy sectors. In 2006, with Alex Wyatt he co-founded Climate Bridge, a developer of clean energy projects in China and around the world, with offices in four countries. Also in 2006, with Robin Smale he co-founded Vivid Economics, a boutique economics consultancy where he has worked with private sector (and government) clients on strategy in relation to market structure and resource, energy and environmental issues.

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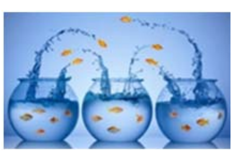

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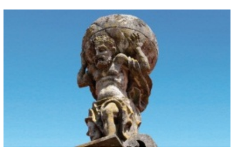

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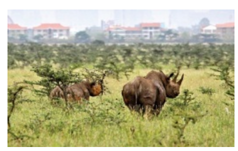

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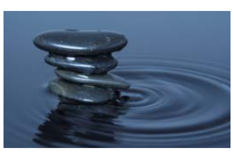

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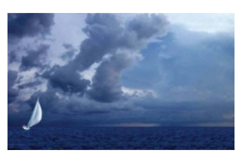

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Key Insights regarding the future of Climate Change

REGULATION

In 1988, the IPCC was created to assess the science of climate change and look at whether formal diplomatic talks would need to be undertaken to discuss the issue of greenhouse gas emissions. / In December 2015 heads of representative states will meet in Paris to discuss setting up a new binding international agreement with the aim of keeping global warming to 2°C and mobilize funds to allow developing countries to both adapt to and mitigate climate change impacts.

GLOBAL REACH

The world can largely ignore the implications for emissions and feed an energy-hungry planet with cheap fossil fuels to drive global economic growth. / The cost of inaction is not only the total energy spend on capex and fuel. The overall costs and risks of climate change including externalities such as health and environmental effects could total 0.7% to 2.5% of global GDP in 2060.

COMMODITIES

Emissions contained in current 'reserves' figures are around three times higher than the so-called 'carbon budget'. / Switching to a low carbon energy future means that significant fossil fuels that would otherwise have been burnt will be left underground. Some studies suggest that globally a third of oil reserves, half of gas reserves and over 80% of current coal reserves would have to remain unused from 2010 to 2060 to have a chance of meeting the 2°C target.