THE **NEW** CLIMATE **ECONOMY**

The Global Commission on the Economy and Climate

Technical Note

Infrastructure investment needs of a low-carbon scenario

NEW CLIMATE ECONOMY PROJECT

CONTENTS

Page

Disclaimer

This technical note supplements research conducted for the Global Commission on the Economy and Climate. The New Climate Economy project is pleased to co-publish it as part of its commitment to provide further evidence on and stimulate debate about the issues covered in our report ***Better Growth, Better Climate***.

Suggested Citation

Global Commission on the Economy and Climate. *New Climate Economy Technical Note: Infrastructure investment needs of a low-carbon scenario.* November 2014.

1. INTRODUCTION

This note describes the Commission's assessment of future infrastructure investment needs. It presents projections for a baseline scenario, and the estimated incremental investment required for a low-carbon scenario.[1] It sets out the sources used and provides an overview of the estimates and modelling undertaken by the New Climate Economy (NCE) network.[2]

The extent of future investment needs are highly uncertain, and projections differ depending on methodology and assumptions. Past projections have often been proved wrong, which is one reason why the NCE project does not generally consider the notion of a "business-as-usual" development either plausible or even helpful. The estimates presented here therefore should not be regarded as an attempt at precise projections, but as a broad indication of the approximate magnitude of investment needs for a baseline and low-carbon scenario. In addition, we emphasise that estimates of infrastructure investment needs in a low-carbon scenario are not equivalent to the macroeconomic costs of a low-carbon transition. The change to investment under a low-carbon scenario is one of many factors that influence the eventual impact on GDP and other indicators of economic performance or welfare impacts.

We use a broad definition of infrastructure encompassing a range of the basic physical structures and facilities (e.g. buildings, roads, power plants) needed for the operation of a society.[3] The estimates include energy end-use sectors, such as buildings, industry and transport, which are sometimes not considered in global infrastructure estimates. While the intended coverage is broad, lack of data sets some limits. In particular, there are gaps in projections for investment in the construction of buildings, in industrial facilities and irrigation infrastructure.[4] Investments in climate adaptation are also not considered here.

The two principal sources for the estimates are work by the Organisation for Economic Co-operation and Development (OECD) (for roads, railways, airports, ports, telecommunications and water/waste) and the International Energy Agency (IEA) (for power generation, electricity networks, and energy end-use investment for buildings, industry and transport). Where sectors are comparable, our estimates are in line with the estimates presented by the Intergovernmental Panel on Climate Change (IPCC) in the *Fifth Assessment Report* (which also draws on data from the IEA).

We complement these estimates with analysis by the Climate Policy Initiative (CPI), one of the NCE partner organisations (for investment in upstream fossil fuel extraction and transport and operating expenses). CPI conducted its own modelling to highlight the cost differentials between a baseline and low-carbon scenario, including estimates for investment in the supply chain of fossil fuels, on operating expenditures for low-carbon and fossil fuel-based technologies, and the financial costs of stranded assets[5] (see Annex for a description). CPI's modelling covers two specific elements: the investment needs impact of a switch from fossil fuels to renewable, and the reduction of oil use in the transport sector.

We present results for the time period 2015–2030. To ensure consistency, all estimates are shown in trillion US$ and were converted to the same base year (2010) by applying the world average consumption price index from the International Monetary Fund (IMF).

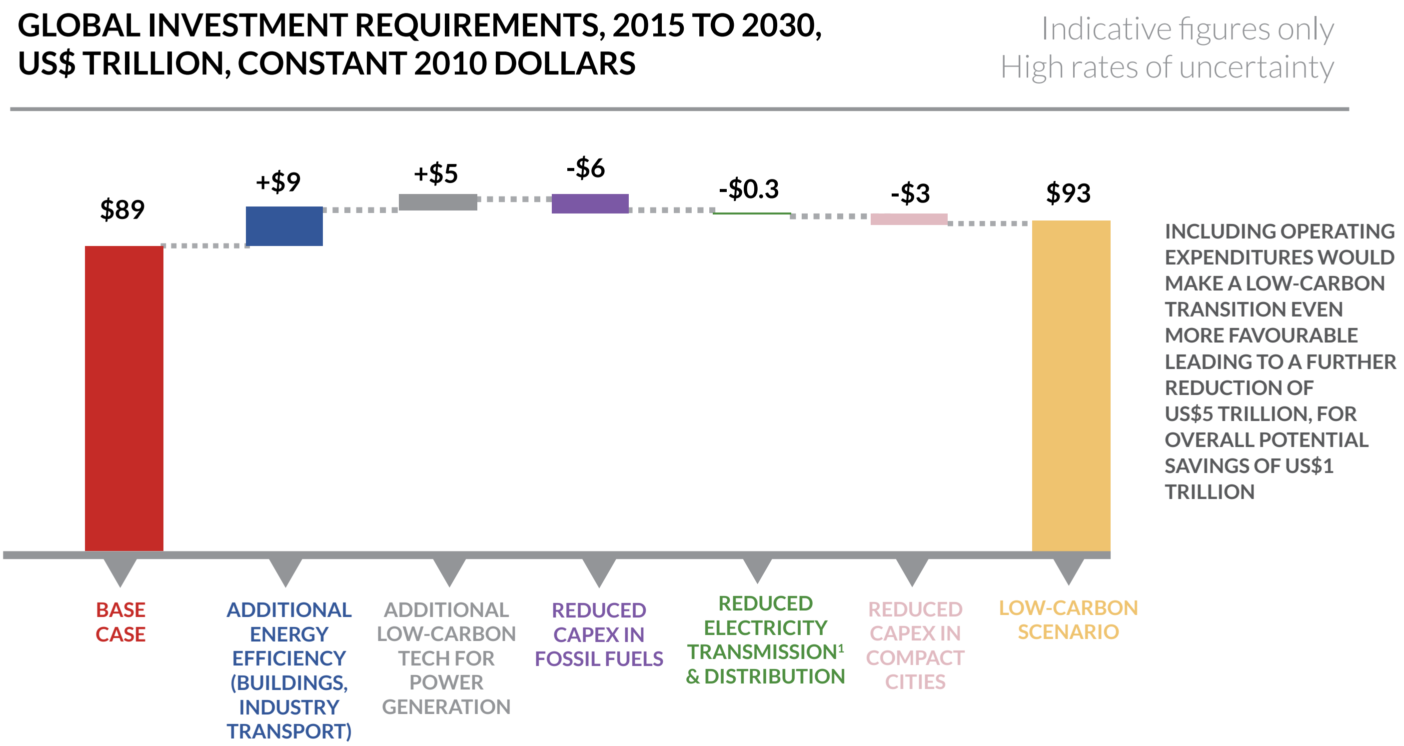
2. SUMMARY FINDINGS

Two key findings arise from our work on infrastructure:

1. There are large infrastructure investment needs over the next 15 years, totalling approximately US$90 trillion between 2015 and 2030. Developed countries have ageing infrastructure that needs to be replaced and developing countries will continue to invest in rapidly expanding their infrastructure, all in the context of a growing global population and increasing urbanisation.
2. The estimates outlined in this note suggest that a low-carbon pathway has incremental infrastructure investment requirements of US$4 trillion between 2015 and 2030, an increase of less than 5% on baseline levels. Other studies have suggested estimates that are even lower.[6]

Figure 1 sets out the summary of our analysis which is outlined in further detail on the following page.

INFRASTRUCTURE CAPITAL SPEND IS 1% LOWER IN A LOW-CARBON SCENARIO



[1] Net electricity transmission and distribution costs are decreased due to higher energy efficiency lowering overall energy demand compared with the base case. This efficiency effect outweighs the increased investment for renewables integration. Source: Climate Policy Institute and New Climate Economy analysis based on data from IEA, 2012, and OECD, 2006, 2012.[7]

The low-carbon scenario sees increases in energy efficiency and low-carbon power generation. These increases could be partially offset by savings in several other components including reduced investment in fossil-fuel power plants and savings along the supply chain (from exploration to transport) of fossil fuels due to the reduced demand for fossil fuels. There is also reduced investment in electricity transmission and distribution, as the savings from reduced demand through greater energy efficiency outweigh the incremental investment in the electricity grid required to make use of renewable energy sources. Finally, the development of more compact and connected cities has the potential to reduce overall infrastructure requirements for roads, telecommunications, water and waste treatment through more efficient infrastructure delivery.

The above results cover capital expenditure (capex), i.e. the expenditure involved in the creation or refurbishment of infrastructure. They do not reflect operating expenditure (opex), i.e. the spending required to ensure their day-to-day functioning and operation. Our estimates suggest opex in the low-carbon scenario would be US$5.1 trillion lower over the period 2015–2030, primarily from savings on fuel expenditure. For comparison, the incremental investment requirements in the low-carbon scenario are US$4.1 trillion over the same period (or US$273 billion per year on average).[8] The opex savings estimates therefore are larger than the increase in capex, although the timing is different, with investments required earlier in the period.

3. THE BASE CASE PROJECTION

The base case estimates draw on the following scenarios:

For estimates derived from the IEA, the base case follows estimates from the "current policy" scenario from the IEA's *World Energy Outlook 2013*, and the "six degrees" scenario (6DS) from the IEA's *Energy Technology Perspectives 2012*.[9] These are based on the continuation of current trends, including that only policies already implemented continue into the future and no new policy action is introduced to address climate change and energy security concerns. In climate terms, these scenarios are broadly consistent with one another and in line with a long-term temperature increase of 6°C.[10]

The estimates used from the OECD are based on an evaluation of historic infrastructure expenditures and do not take climate action into consideration. They thus follow similar principles to the IEA's "current policies/6DS" scenarios, insofar as continuation of historic trends in expenditures are a reasonable proxy for no new climate policy.

We explain the sector estimates further below.

3.1 ENERGY

Estimates of the energy sector include investment needs for power generation, electricity transmission and distribution (T&D), the fossil fuel supply chain, as well as energy infrastructure in energy end-use sectors such as buildings, industry and transport.

Investment needs for power generation include fossil-fuel power plants and power generation from renewable energies (i.e. solar, wind, geothermal, bioenergy and hydropower), nuclear energy, and biofuels for transportation. Carbon capture and storage (CCS) is included as a low-carbon technology. Base case estimates for power generation and electricity T&D are from the IEA's "6DS" scenario.

The supply chain of fossil fuels includes investment needs for upstream extraction and exploration and transport of fossil fuels. Estimates for oil include upstream, refining and transport investment; for gas upstream, T&D and liquefied natural gas (LNG) investment. For coal, only mining investment is included. Estimates for investment in upstream and transport of fossil fuels come from CPI's own modelling consistent with the "current policies/6DS" scenario of the IEA (as described above).

Energy infrastructure investment in sectors such as buildings, industry and transport includes investment related to energy use in these energy consumption sectors. In the case of buildings, as an example, this covers investment in ventilation and air-conditioning (HVAC) systems or light bulbs. In transport, investments cover power trains of fossil-fuel light-duty vehicles and low-carbon light-duty vehicles, as well as full costs of planes, ships and rail. Estimates are derived from the IEA "6DS" scenario.

3.2 TRANSPORT

The transport infrastructure estimates include road, rail, airports and ports. Estimates for road infrastructure were taken from OECD (2006), *Infrastructure to 2030*, whereas for rail, airports and ports estimates come from OECD (2012), *Strategic Transport Infrastructure Needs to 2030*.[11] These are the most recent publications for which estimates in the respective categories are available.

Road and rail infrastructure includes investment in new construction as well as maintenance costs. Infrastructure requirements for airports and ports follow a projected doubling in air passenger traffic, a tripling of air freight and a quadrupling of port handling of maritime containers worldwide by 2030.

3.3 WATER AND WASTE

Water and waste infrastructure estimates are taken from OECD (2006), Infrastructure to 2030. Although these estimates are dated, they are the most comprehensive estimates available.

The scope of these estimates is principally urban water services and to a lesser extent rural water services. Four major urban water systems are included, namely wastewater systems, water supply networks, water abstraction for human needs and for agricultural use.[12]

The estimates are based on government actual and budgeted infrastructure spending levels across most OECD countries, BRIC countries (Brazil, Russia, India and China) and a few other developing countries, and are extrapolated out to future years by the OECD.

3.4 TELECOMMUNICATIONS

Telecommunications infrastructure estimates are taken from OECD, 2006, Infrastructure to 2030. They cover only OECD countries, Brazil, China and India.

The scope includes fixed-line telephony and data, mobile telephony and data – including alternative wireless technologies beyond cellular mobile – and broadband mobile communications, especially wireless broadband.

Table 1

Summary table for infrastructure investment needs – base case projections

Type of investment (as shown on chart)	Sub-type of investment	Estimate for 2015–2030 (trillion US$ 2010)	Notes: what is included and rationale for source used	Source
Transport	Road	6.2	Investment in all countries for roads – new construction and maintenance. We have used the most up-to-date publications possible, but where estimates did not include a sector, we have used previous publications, e.g. OECD (2012), *Strategic Transport Infrastructure Needs to 2030*, does not cover road investment so we have used OECD (2006).	*OECD, 2006. Infrastructure to 2030.*
Transport	Rail, airports, ports	7.47 (Rail: 4.69, Airports: 2.08, Ports: 0.7)	New construction as well as maintenance for rail. Infrastructure requirements for airports and ports follow projected demand increases for these types of transport.	*OECD, 2012. Strategic Transport Infrastructure Needs to 2030.*
Water and waste	Water and waste	21.34	Urban water services and to a lesser extent rural water services. These estimates are based on government actual and budgeted infrastructure spending levels across most OECD countries, BRIC countries and a few other developing countries, and are extrapolated out to future years by the OECD.	OECD, 2006. *Infrastructure to 2030.*
Energy	Power generation	5.78 (Fossil fuels: 2.98, Nuclear: 0.62, Renewables: 2.16, CCS: 0.02)	Fossil-fuel power plants (oil, gas, coal-fuelled), renewables, nuclear, CCS and biofuels.	IEA, 2012. *Energy Technology Perspectives 2012.*
Energy	Electricity T&D	4.32	Electricity T&D.	IEA, 2012. *Energy Technology Perspectives 2012.*
Energy	Oil and gas	11.55 (Oil: 7.14, Gas: 4.41)	Oil includes upstream, refining and transport investment. Gas includes upstream, transmission and distribution, and LNG investment.	CPI based on its methodology (see Annex for more details).
Energy	Coal	0.97	Investment in coal mining.	CPI based on its own methodology (see Annex for details).
Energy	Transport engines – Energy use	14.06	Power trains for fossil-fuel light-duty vehicles, low-carbon light-duty vehicles, as well as full vehicle costs of planes, ships and rail.	IEA, 2012. ***Energy Technology Perspectives 2012.***
Energy	Buildings – Energy use	5.83	Investments related to energy use in buildings, e.g. ventilation and air-conditioning (HVAC) systems.	IEA, 2012. *Energy Technology Perspectives 2012.*
Energy	Industry – Energy use	3.95	Investments related to energy use in the top five most energy-intensive sectors: Chemicals and petrochemicals, Iron and steel, Pulp and paper, Cement, and Aluminium.	IEA, 2012. *Energy Technology Perspectives 2012.*
Telecoms		7.14	Fixed-line telephony and data, mobile telephony and data – including alternative wireless technologies beyond cellular mobile – and broadband mobile communications, especially wireless broadband. Covers OECD countries plus Brazil, China and India, and therefore underestimates global investment requirements.	
Total Base-Case Requirements		**88.61**		**OECD, 2006 and 2012; IEA, 2012; CPI own analysis.**

4. MEASURING THE INFRASTRUCTURE INVESTMENT NEEDS OF A LOW-CARBON SCENARIO

NCE has used existing estimates to determine the investment needs associated with a low-carbon transition, focusing on the primary actions outlined in the Commission's report. These investment needs are typically based on the IEA's "2DS/450 ppm" scenario,[13] which corresponds to a 80% chance of limiting average global temperature increases to 2°C.[14] NCE used where possible the same sources for estimates in the base case and low-carbon scenario. For example, IEA's *Energy Technology Perspectives 2012* is used for both the baseline and low-carbon estimates. There are, however, categories for which we only have base case data without any corresponding low-carbon scenarios. Here, low-carbon estimates are based on NCE's own analysis versus an aggregate baseline which draws on OECD and IEA estimates.

The estimates of investment needs in a low-carbon scenario include:

- Incremental US$4.7 trillion investment for the deployment of low-carbon technologies in the energy sector
- Incremental US$8.8 trillion investment from energy efficiency improvements
- A reduction of US$0.3 trillion of investment in electricity transmission and distribution
- Reduced investment of US$2 trillion for power generation from fossil fuels and of US$3.7 trillion in the supply chain of fossil fuels
- Reduced investment of US$3 trillion due to more compact, connected urban development
- Reduced operating expenditure associated with a low-carbon transition

Details of the estimates for main cost/savings components are provided below.

4.1 INCREMENTAL INVESTMENT FOR THE DEPLOYMENT OF LOW-CARBON TECHNOLOGIES IN THE ENERGY SECTOR

In the "6DS" scenario of the IEA'S *Energy Technology Perspectives 2012* the share of renewable energy increases from 19% to 24% from 2009 to 2050 and no CCS is deployed. In contrast, the "2DS" scenario sees the share of renewables reaching 57% of the world's electricity mix while fossil-fuel power plants equipped with CCS contribute 14%. The associated incremental capital expenditure to reach this deployment of low-carbon technologies in the 2°C scenario amounts to US$4.7 trillion in the period 2015–2030. Low-carbon technologies include renewables (+ biofuels), nuclear energy and CCS. [15]

4.2 INCREMENTAL INVESTMENT FROM ENERGY EFFICIENCY IMPROVEMENTS

Total primary energy supply in the "6DS" scenario of the IEA's Energy Technology Perspectives 2012 will increase by 85% up until 2050 as a result of energy demand increases. Due to improved energy efficiency, this increase can be kept to 35% in the "2DS" scenario. Incremental investment accrues in the energy consumption sectors, such as buildings, industry and transport, where energy efficiency improvements can be realised. In the buildings and industry sectors these incremental investments amount to US$4.73 trillion and US$0.61 trillion respectively. The incremental capital expenditure in the transport sector, mainly by improving the energy efficiency of transport engines, amounts to US$3.46 trillion.[16]

Overall, incremental investment for energy efficiency improvements are in the order of US$8.8 trillion from 2015 to 2030.

4.3 REDUCED INVESTMENT ON ELECTRICITY TRANSMISSION AND DISTRIBUTION

Deployment of low-carbon technologies as well as energy efficiency improvements make different investment demands on electricity transmission and distribution. The integration of intermittent renewable energy sources into the electricity grid leads to incremental investment needs in assets such as smart grids or electricity storage. Energy efficiency improvements as mentioned above lead to reduced capacity additions compared with the base case and related lower investment amounts required to extend transmission and distribution networks. The IEA in their "2DS" scenario projects that the savings from energy efficiency will outweigh the incremental investment in the electricity grid needed to integrate intermittent renewable energy sources in the period 2015–2030. Reduced investment amounts to US$0.3 trillion.

4.4 REDUCED INVESTMENT FOR POWER GENERATION FROM FOSSIL FUELS AND IN THE SUPPLY CHAIN OF FOSSIL FUELS

The reduced share of fossil fuel power generation in the energy mix in the IEA's "2DS" scenario leads to lower infrastructure investment needs in fossil-fuel power plants. These reduced investments amount to US$2.0 trillion from 2015 to 2030.

Based on CPI's modelling, lower investment needs in the supply chain of fossil fuels are a result of a low-carbon scenario as well. CPI estimates the demand for oil, natural gas and coal to be roughly 12%, 9% and 14% lower, respectively, in a low-carbon scenario by 2030, compared with the baseline scenario. In addition, demand for electricity is 26% lower by 2030 compared with the base case. The related lower investment required in the supply chain for fossil fuels amounts to US$3.7 trillion. Estimates are from CPI and are based on the IEA's *World Energy Outlook 2013* "450ppm" scenario.

Overall, reduced investment needs in fossil-fuel power plants and in the supply chain of fossil fuels add up to US$5.7 trillion in the period 2015–2030.

4.5 REDUCED INVESTMENT DUE TO MORE COMPACT, CONNECTED URBAN DEVELOPMENT

One of the NCE's key findings is the important role that more compact, connected cities could play in reducing the overall infrastructure requirement in urban areas. No robust estimates exist of the impact of compact urban form on investment costs and its consistency with a 2°C pathway. NCE used a simple methodology to develop an order of magnitude estimate of the infrastructure investment requirements when cities follow a more compact model.

First, baseline estimates for telecommunications, buildings, water and waste, as well as road investment were taken as the basis for a global infrastructure baseline incorporating the sectors likely to be most significantly impacted by more compact urban development. For a conservative estimate, energy, industry, airports, ports and rail were not included, and transport engines were excluded to avoid double-counting.

We then assume that roughly two-thirds of the investment requirement in these sectors will be in urban areas. For comparison, work by Oxford Economics for the Commission suggests that approximately two-thirds of global economic growth to 2030 will be in cities with populations greater than 500,000. If small urban areas are included the number is closer to 90%.[17] Given these numbers, attribution of two-thirds of investment in the relevant infrastructure categories may be an underestimate.

This share is applied to telecommunications, buildings[18] and road investment. The full water and waste estimate from the OECD is included in the baseline, as their estimate refers primarily to investment in urban areas.[19]

We then assume that 10% of these infrastructure investment costs can be saved from a more compact urban model. For comparison, existing evidence of the impact of compact cities on infrastructure requirements suggests that capital expenditure across major sectors can be reduced by up to one-third versus more dispersed development. For example:

- The Delaware Valley Regional Planning Commission estimated the infrastructure costs of five alternative development scenarios for the Philadelphia region. They found that roads, schools and utilities would cost US$25,000 per household for the most compact scenario which emphasised urban infill, compared with US$45,000 for the most sprawled scenario.[20]
- Burchell and Mukherji (2003) found that sprawl increases local road lane-miles by 10%, annual public service costs by about 10%, and housing costs by about 8%.[21]
- More compact development could save Calgary, Canada about a third in capital costs for roads, transit services, water and wastewater, emergency response, recreation services and schools.[22]
- Analysis of options for accommodating an additional 1.25 million residents and 800,000 jobs in Central Texas found that infrastructure costs would be US$3.2 billion (US$2,560 per capita) under a scenario that concentrates development in existing urban areas, compared with US$10.7 billion (US$8,560 per capita) if current lower-density development trends continue.[23]
- There is a dearth of estimates of infrastructure investment savings from more compact, connected urban development outside the US and Canada. However, recent World Bank research from China indicates significant savings. This research indicates that China could save up to US$1.4 trillion in infrastructure spending up to 2030 if it pursued a more compact, transit-oriented urban model – equivalent to around 15% of China's GDP in 2013.[24]

Applying this reduction to all new urban development between 2015 and 2030 would reduce investment requirements by US$3.4 trillion. While this scenario is ambitious, the estimate is tempered by the use of a conservative savings assumption (i.e.

some urban development is likely to be more dispersed generating fewer cost savings, and some could generate cost savings well in excess of 10%). Also, reduced investment needs for global construction was estimated to amount to around US$5.4 trillion in 2010. The savings available by reducing this amount through more compact urban development have not been included here. Nonetheless, this estimate should still be treated with caution as indicative and illustrative of potential savings.

4.6 REDUCED OPERATIONAL EXPENDITURES FROM A LOW-CARBON TRANSITION

Operational expenditures (opex) are another important cost component of a low-carbon transition. CPI modelled the changed operational expenditures for two low-carbon transitions compared with a baseline projection. The first is the switch from fossil fuels to renewable energies in electricity generation, and the second is the reduction of oil in the transport sector by increasing the share of low-carbon vehicles and improving mass transit. The modelling covers the reduction in operating expenditures from fossil-fuel power plants and vehicles but also the increments for the operating and maintenance of renewable electricity generating plant and low-carbon vehicles. Baseline projections are based on IEA's *World Energy Outlook 2013* "current policies" scenario. Estimates for a low-carbon scenario are based on IEA's *World Energy Outlook 2013* "450ppm" scenario.

The results for opex following a fossil fuels to renewables transition in the power sector suggest reduced opex from coal mining and domestic transport of US$2.38 trillion, from international transport of coal of US$0.34 trillion, from gas of US$0.17 trillion, and from fossil fuel generation of US$1.19 trillion in the period 2015–2030. Incremental opex from nuclear power amounts to US$0.19 trillion and from renewables to US$0.40 trillion.[25] Overall, a switch from fossil fuels to renewables leads to net opex reductions of US$3.49 trillion.

The results for opex following the reduced use of oil in the transport sector suggests reduced expenditures from oil of US$2.65 trillion and from gasoline engines of US$0.53 trillion. This assumes no changes in the price of oil relative to the baseline scenario. Incremental opex from diesel engines amount to US$0.04 trillion, from LPG/CNG to US$0.12 trillion, from hybrid vehicles to US$0.6 trillion, from plug-in and electric vehicles to US$0.41 trillion, from fuel cell vehicles to US$0.04 trillion, and from plane, ship and rail to US$0.32 trillion. Overall, a reduction of oil in the transport sector in line with a 2°C scenario leads to a net reduction in opex of US$1.65 trillion.

Combined, both transitions lead to reduced opex of US$5.14 trillion in the period 2015–2030.[26]

Table 2

Summary table for infrastructure investment needs – low-carbon scenario

Category in chart	Estimate for 2015–2030 (trillion US$ 2010)	Sub-categories and what is included	Explanation for effects	Source
Infrastructure for energy efficiency	+8.8	Buildings, industry, transport engines.	Incremental investment needs to improve energy efficiency.	IEA, 2012. *Energy Technology Perspectives 2012.*
Low-carbon technology	+4.7	Renewable energies (including biofuels), CCS and nuclear.	Incremental investment needs to deploy low-carbon technologies.	IEA, 2012. *Energy Technology Perspectives 2012.*
Reduced capex from fossil fuels	-2.0	Reduced infrastructure spend on fossil-fuel power plants.	Reduced investment from decrease of fossil-fuel power generation and improved energy efficiency.	IEA, 2012. *Energy Technology Perspectives 2012.*
	-3.7 (Oil: -2.32, Gas: -0.75, Coal: -0.66)	Reduced infrastructure spend on fossil-fuel supply chain: **Oil** includes upstream, refining and transport investment. **Gas** includes upstream, transmission and distribution, and LNG investment. **Coal** includes mining investment.	Reduced investment from decrease in demand for fossil fuels.	CPI based on its own methodology (see Annex for details).
Reduced electricity transmission & distribution costs	-0.3	Electricity T&D.	Energy efficiency savings outweigh increased T&D demand to integrate renewables.	IEA, 2012. *Energy Technology Perspectives 2012.*
Reduced capex from compact cities	-3.4 (up to)	Buildings, telecoms, water and waste, road.	Reduced investment from savings in infrastructure due to a compact urban model.	NCE based on its own methodology (see Annex for details).
Reduced opex from low-carbon transition	(-5.1)	Opex of shift to low-carbon technologies (renewables, low-carbon vehicles) and reduced oil demand in transport sector (low-carbon vehicles).	Reduced opex due to switch from fossil fuel to low-carbon technologies and reduction of oil in transport sector.	CPI based on its own methodology (see Annex for details).
Total incremental costs/savings of a low-carbon scenario (with opex included in brackets)	+4.1 (-1)			**IEA 2012, CPI own analysis, NCE own analysis.**

ANNEX: CLIMATE POLICY INITIATIVE MODELLING

NCE used estimates from one of its partner organisations – the Climate Policy Initiative (CPI) – to provide a variety of the baseline and low-carbon scenario estimates outlined above. Throughout Chapter 6: Finance in the report, infrastructure investment estimates are based on the same sources to ensure consistency and comparability. However, there are a few discrepancies between NCE's own analysis in Figure 1 of the chapter and CPI's analysis which is included in the rest of the chapter, in particular the time horizon as well as the scope of the analysis. NCE uses a time horizon from 2015 to 2030 whereas CPI has a time horizon from 2015 to 2035. NCE shows infrastructure requirements for a comprehensive list of different sectors while CPI's focus is on the energy and transport sector. Finally, NCE reports investment numbers largely based on capital expenditures and only marginally includes operational expenditures. For CPI operational expenditures, as well as other components of estimating the financial impact of a transition such as stranded assets, are considered in their analysis.

CPI estimates are based on its own modelling exercise further outlined below. Its purpose is to show a comprehensive picture of the financial impact of a low-carbon scenario, including estimates for investment in the supply chain of fossil fuels, on operating expenditures for low-carbon and fossil fuel-based technologies, and the financial costs of stranded assets.

CPI has been developing global supply and demand models for oil, gas, coal and power. Four models (two supply and two demand models) have been developed using relatively consensual data from providers and vendors trusted by market professionals and policy-makers alike (IEA, Rystad, Platts and others). From a methodological standpoint, these four models operate in a familiar fashion. Each matches global energy supply and demand over the period 2015–2035 under two different demand scenarios: a business-as-usual and a "450ppm" scenario, both based on IEA *World Energy Outlook 2013* models. Supply is based on existing fossil-fuel reserves (power generation capacity for the power sector) and supply curves (taking into account operating expenses, capital expenditures, transportation costs and government take/taxation). The only major exception to this is the oil model for which CPI explicitly modelled business-as-usual demand and derived "450ppm" scenario demand over 2015–2035. GDP projections used to derive global oil demand have an implicit assumption about future oil prices. To avoid any price effect, CPI explicitly modelled global oil demand based on: (i) GDP growth rates (IMF and OECD); (ii) conversion rates (i.e. oil demand growth to real GDP growth based on IMF, BP and Rystad data); and (iii) adjustment to account for short-term and long-term price sensitivities for all the regions over time.

Supply and demand are then matched depending on: (i) total supply costs; (ii) expected prices for the different markets (domestic versus import/export); (iii) changes in expected supply and demand; (iv) whether or not demand can be met with domestic supply; and (v) whether physical assets (dedicated pipelines, etc.) or contracts/market practice (long-term gas supply contracts indexed on oil prices, etc.) shape future export/import trade. Once supply and demand have been matched, we calculate the value of each country's annual production under each scenario, sum the discounted annual production values to today's money, and assess the magnitude of loss in value to producers because of the change in scenarios (i.e. the stranding).

Details of the estimates for main cost/savings components are provided below.

Building block	Sector	Value	Scenario(s)	Data source	Rationale	Comments
DEMAND	Oil	-16% over 2015–2035	CPI own IEA-compatible scenarios	CPI modelling based on IMF, OECD, BP Statistical Review 2013, Rystad UCube database and IEA's WEO 2013[27]	Need to adjust for implicit oil price effect embedded in GDP projections	Broken down at country level. Note that biofuels and refinery gains are included in total oil demand
	Natural gas	-12% over 2015–2035	"Current policies" scenario (CPS) vs. 450ppm	IEA's WEO 2013 & BP Statistical Review 2013		
	Electricity	-19% over 2015–2035		IEA's WEIO 2014[28]	Reference scenarios	
	Coal	-34% over 2015–2035		IEA's WEO 2013, IEA 2013 Medium-Term Coal Market Report[29] and BP Statistical Review 2013		
SUPPLY	Oil	Equal to global demand	CPI own IEA-compatible scenarios	Rystad UCube database	Need for country-level granularity	-
	Natural gas				Need for country-level granularity	Supply curves for (1) domestic markets, (2) pipeline exports, and (3) LNG exports
	Electricity		CPS vs. 450	Platts World Electric Power Plants database[30]	-	-
	Coal			IEA 2013 Medium-Term Coal Market Report, BGR Energy Study 2013[31] and BP Statistical Review 2013	-	Country-level supply is based on a linear programming model

Building block	Sector	Value	Scenario(s)	Data source	Rationale	Comments
CAPEX	Oil	Country- / year-specific	-	Rystad UCube database	n/a	n/a
	Natural gas				-	Broken down into (1) domestic markets, (2) pipeline exports, and (3) LNG exports
	Electricity	Country- / year-specific		CPI calculations based on IEA , OECD and NEA 2010 cost of generating electricity[32]	-	-
	Coal	Country- / year-specific		CPI calculations based on IEA's WEIO 2014 and IEA 2013 Medium-Term Coal Market Report	-	Distinction between greenfield and brownfield capex
OPEX	Oil	Country- / year-specific	-	Rystad UCube database	-	-
	Natural gas				-	Broken down into (1) domestic markets, (2) pipeline exports, and (3) LNG exports
	Electricity	Country- / year-specific		CPI calculations based on EIA and IEA 2010 cost of generating electricity	-	-
	Coal	Country- / year- / technology-specific		CPI calculations based on IEA WEO 2013 (based on Wood/ McKenzie cash cost curves) and BGR Energy Study 2013	Global cash cost curve	-
TRANSPORTA-TION COSTS	Oil	-	-	-	-	-
	Natural gas	-		-	Pipeline / LNG cost embedded in export prices	-
	Electricity	-		-	-	-
	Coal	Destination- / origin- / year-specific		CoalAge.com and SeaRates.com[33]	-	-

Building block	Sector	Value	Scenario(s)	Data source	Rationale	Comments
GOVERNMENT TAKE	Oil	Country- / year-specific	-	Rystad UCube database	Information readily available in the Rystad UCube database	-
	Natural gas					Broken down into (1) domestic markets, (2) pipeline exports, and (3) LNG exports
	Electricity	-		-	-	-
	Coal	Country-specific		PwC report on global mining taxation[34]	-	-
PRICES	Oil	Country- (netbacks) / scenario- / year-specific	CPI own IEA-compatible scenarios	CPI calculations	-	-
	Natural gas		CPS vs. 450		Depending on supply and demand matching, market structures, and prevailing practice	Three main pricing approaches: (1) netback to global LNG market price (in turn influenced by CPI oil prices), (2) index / long-term contracts, and (3) cost plus
	Electricity	-		Static prices	-	The estimated cost of delivering a MWh of energy from the average advanced CCGT plant operating as baseload generation is used. Static assumptions of future fuel prices are used that differ by region (US, EU, OECD Asia)
	Coal	Market- / country- / scenario- / year-specific		CPI calculations	-	Linear programming model for domestic / seaborne markets

ENDNOTES

[1] NCE is grateful to the individuals that provided inputs and contributions to this note. These include Michael Jakob, Murray Birt, Christopher Kaminker, Robert Youngman, Jane Ellis and Jan Corfee-Morlot. They are, however, not responsible for the accuracy, content, findings or recommendations. The findings do not necessarily reflect their views, or those of the organisations they represent. Although the analysis draws on data from the IEA and OECD, the analysis has been carried out by the NCE project and is not endorsed by the IEA or OECD.

[2] Throughout the note, the low-carbon scenario is broadly consistent with the IEA's "2DS/450 ppm" scenario and describes the infrastructure investment needs for a pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO2. For further information, please see: http://www.iea.org/publications/scenariosandprojections/.

[3] Oxford Dictionaries, see http://www.oxforddictionaries.com/definition/english/infrastructure.

[4] Current annual global construction spending has been estimated in the order of US$5.4 trillion; see: IHS Global Insight, 2010, Global Construction Outlook: Executive Overview. Available at: http://www.ihs.com/products/global-insight/industry/construction/global.aspx. The OECD does not provide an in-depth consideration of irrigation in their water estimates (see note 10 for more information).

[5] To stay within a reasonable carbon emissions budget consistent with a 2°C or less rise in global temperatures, certain assets – including coal mines, oil fields – will need to remain underexploited. To the extent that investors or governments have invested in, or otherwise relied upon, assets that are then left underexploited to reduce the threat of climate change, the stranding of assets describes a decline in the value of some fossil fuel assets from their perceived value in a world without carbon constraints.

[6] Kennedy, C. and Corfee-Morlot, J., 2012. *Mobilising Investment in Low Carbon, Climate Resilient Infrastructure*. OECD Environment Working Paper No. 46. OECD Publishing, Paris. DOI:10.1787/5k8zm3gxxmnq-en.

Kennedy, C. and Corfee-Morlot, J., 2013. *Past performance and future needs for low carbon climate resilient infrastructure – An investment perspective*. Energy Policy, 59. 773–783. DOI:10.1016/j.enpol.2013.04.031.

[7] International Energy Agency (IEA), 2012. *Energy Technology Perspectives: How to Secure a Clean Energy Future*. Paris. Available at: http://www.iea.org/etp/etp2012/.

Organisation for Economic Co-operation and Development (OECD), 2012. *Strategic Transport Infrastructure Needs to 2030*. Paris. Available at: http://www.oecd.org/futures/infrastructureto2030/strategictransportinfrastructureneedsto2030.htm.

Organisation for Economic Co-operation and Development (OECD), 2006. *Infrastructure to 2030*. Paris. Available at: http://www.oecd.org/futures/infrastructureto2030.

[8] The IEA estimates total fuel savings alone of US$100 trillion between 2010 and 2050, or an annual average of US$1.5 trillion. See: International Energy Agency (IEA), 2012. *Energy Technology Perspectives 2012*. IEA, Paris.

The modelling by CPI used here also considers the reduction in operating expenditures from fossil-fuel power plants and vehicles, as well as the increase for the operating and maintenance of renewables and low-carbon vehicles.

[9] International Energy Agency (IEA), 2013. *World Energy Outlook 2013*. IEA, Paris. Available at: http://www.worldenergyoutlook.org/publications/weo-2013/.

IEA, 2012. *Energy Technology Perspectives 2012*.

[10] For a summary of IEA scenarios and how these scenarios relate to each other, please see: http://www.iea.org/publications/scenariosandprojections/.

[11] Organisation for Economic Co-operation and Development (OECD), 2006. *Infrastructure to 2030*. OECD, Paris.

Organisation for Economic Co-operation and Development (OECD), 2012. *Strategic Transport Infrastructure Needs to 2030*. OECD, Paris.

[12] OECD, 2006, *Infrastructure to 2030*, provides a further specification of the scope of their water estimates: "1. Water abstracted for agricultural use – for rural communities and small urban areas. Most of this is groundwater. 2. Water resources – abstraction (and possibly storage) for human needs. The source can be upland rivers, lakes, lowland surface water, groundwater, sea or brackish sources or from evaporation systems. 3. Water supply network, including inputs from abstraction, treatment,

ENDNOTES

storage and distribution, and outputs, including management of residual sludge. 4. Wastewater system, including stormwater and sanitary drainage, treatment, effluent disposal and management of residual sludge."

[13] The "2DS" and "450ppm" scenarios are two consistent scenarios. IEA uses these two titles throughout different publications.

[14] For further information, please see: http://www.iea.org/publications/scenariosandprojections/. Here, the IEA provides a description of its low-carbon scenario, in particular its probability to limit global average temperatures to 2°C.

[15] Chapter 4: Energy in the main report uses CCS investment estimates from the "450ppm" scenario from the IEA's *World Energy Investment Outlook 2014* (WEIO 2014). The difference between these and the estimates of the IEA's *Energy Technology Perspectives 2012* (ETP 2012) are minimal. Investment estimates for CCS are US$1.3 trillion up until 2035 (ETP 2012) compared with US$1.4 trillion up until 2035 (WEIO 2014).

[16] It is worth noting that for efficiency improvements in the transport sector the IEA factors in the need of travel growth to be slowed via city planning and demand management (Avoid), as well as via a shift of goods transport from trucks to rail (Shift). This will lead to an overall reduction in vehicle ownership compared with the baseline projection and broadly in line with assumptions in other NCE technical notes. The incremental investment estimate is thus a net result of incremental investment in transport engines minus reduced investment from lower vehicle ownership.

[17] Oxford Economics modelling in partnership with LSE Cities for NCE. Further details are outlined in: Floater, G., Rode, P., Robert, A., Kennedy, C., Hoornweg, D., Slavcheva, R. and Godfrey, N., 2014 (forthcoming). *Cities and the New Climate Economy: the transformative role of global urban growth*. New Climate Economy contributing paper. LSE Cities, London School of Economics and Political Science. To be available at: http://newclimateeconomy.report.

[18] For buildings, the IEA does not take an effect of compact cities into consideration. The evolution of energy consumption is instead related to the increase in population and number of households, income growth, increase in appliance ownership, and energy efficiency improvements. See: IEA, 2012. *Energy Technology Perspectives 2012*, pp. 457–461.

[19] OECD, 2006. *Infrastructure to 2030*. "The sectoral scope of this report is principally urban water services and to a lesser extent rural water services. However, with some 75% of the world's water being used for agriculture, there are issues of allocation and competition for resources (quantity) as well as water quality. Thus agricultural consumption cannot be ignored, even if in-depth consideration of the infrastructure needed for irrigation lies outside the scope of this report."

[20] Delaware Valley Regional Planning Commission (DVRPC), 2003. *Regional Analysis of What-If Transportation Scenarios*. Available at: www.dvrpc.org/reports/03020.pdf.

[21] Burchell, R. and Mukherji, S., 2003. *Conventional Development Versus Managed Growth: The Costs of Sprawl*. American Journal of Public Health, 93 (9). 1534–1540. DOI:10.2105/AJPH.93.9.1534.

[22] IBI, 2008. *Implications of Alternative Growth Patterns on Infrastructure Costs*. Plan-It Calgary, City of Calgary. Available at: http://www.reconnectingamerica.org/assets/Uploads/planitcalgarycoststudyanalysisaprilthird.pdf.

[23] Envision Central Texas, 2003. Scenario Briefing Packet. Available at: http://content.lib.utah.edu/cdm/ref/collection/FHWA/id/1421.

[24] World Bank, 2014. *Urban China: Toward Efficient, Inclusive, and Sustainable Urbanization*. World Bank, Washington DC.

[25] Opex from CCS were not considered as part of the modelling.

[26] Values for opex were not discounted.

[27] BP, *Statistical Review of World Energy 2013*. Available at: http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html.

Rystad U-Cube database. Available at: http://www.rystadenergy.com/Databases/UCube.

IEA, 2013. *World Energy Outlook (WEO) 2013*. IEA, Paris. Available at: http://www.worldenergyoutlook.org/publications/weo-2013/.

[28] IEA, 2014. *World Energy Investment Outlook (WEIO) 2014*. IEA, Paris. Available at: http://www.worldenergyoutlook.org/investment/.

ENDNOTES

[29] IEA, 2013. *Medium-Term Coal Market Report 2013*. Available at: http://www.iea.org/w/bookshop/add.aspx?id=461.

[30] Platts, 2014. *World Electric Power Plants database*. Available at: http://www.platts.com/products/world-electric-power-plants-database.

[31] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2013. E*nergy Study 2013*. Available at: http://www.bgr.bund.de/EN/Themen/Energie/Downloads/energiestudie_2013_en.pdf?__blob=publicationFile&v=2.

[32] IEA, OECD and Nuclear Energy Action (NEA), 2010. *Projected Costs of Generating Electricity – 2010 Edition*. Available at: http://www.iea.org/publications/freepublications/publication/projected_costs.pdf and http://www.eia.gov/electricity/.

[33] Transportation costs were retrieved from SeaRates, see: www.searates.com; information on destination and origin were retrieved from CoalAge, please see: www.coalage.com.

[34] PwC, 2012. *Corporate income taxes, mining royalties and other mining taxes: A summary of rates and rules in selected countries*. Available at: http://www.pwc.com/en_GX/gx/energy-utilities-mining/publications/pdf/pwc-gx-miining-taxes-and-royalties.pdf.

ABOUT THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate is a major new international initiative to examine the economic benefits and costs of acting on climate change. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers, and leaders in the fields of economics, business and finance.

The New Climate Economy (NCE) is the Commission's flagship project. It provides independent and authoritative evidence on the relationship between actions which can strengthen economic performance and those which reduce the risk of climate change. It reported in September 2014 in advance of the UN Climate Summit. It aims to influence global debate about the future of economic growth and climate action.