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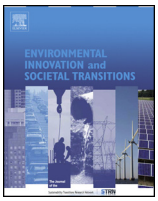

Analysis

Post carbon pathways: A meta-analysis of 18 large-scale post carbon economy transition strategies

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ABSTRACT

This article summarises findings from a review of eighteen large-scale post-carbon transition strategies, from government and non-government sources. It is informed by analysis of policies and reports identifying one or more integrated pathways for achieving dramatic greenhouse gas emissions reductions within national or supranational jurisdictions. For each strategy we considered assumptions and priorities regarding: targets, technology; economics and financing; equity; governance; and social and political change. We describe lessons from analysis of these attempts to articulate and stimulate integrated actions for post-carbon transitions and point to areas for further exploration. A crucial difference was identified between strategies advocating an incremental and evolutionary approach to emissions reductions and those advocating more rapid and transformational change. This highlights the challenging and urgent task of understanding how to bridge the gap between physical requirements of action to prevent runaway climate change and societal support for action at that speed and scale.

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1. Introduction

The concept and language of 'post-carbon futures' is being used in an increasingly broad range of settings (see, for example, European Commission, 2007; Heinberg and Lerch, 2010) to communicate and emphasise the importance of systemic transformations leading to 'a world in which we are no longer dependent on hydrocarbon fuels, and no longer emitting climate-changing levels of carbon into the atmosphere' (Post Carbon Institute, ND). Globally, an increasing number of detailed policy road maps and reports are being developed in response to the necessity and urgency of enacting a rapid transition to a just and sustainable post-carbon future. While they vary significantly in scope, levels of ambition, and methodologies, these documented strategies can contribute to a clearer understanding of the steps required and demonstrate what is possible in achieving post-carbon transitions.

Acknowledging this, a review of eighteen large-scale post-carbon transition strategies, from both government and non-government sources, was conducted, entitled 'Post Carbon Pathways'.[2] The review focused on identifying a set of the most ambitious strategies, at global, regional or national scales, for reducing emissions across the whole economy or, in some cases, only the energy sector. Nine of the selected post-carbon economy transition strategies were developed by governing institutions with the authority and intention to implement the strategy. The remaining nine are hypothetical strategies, in the form of detailed reports, books, or journal articles, developed by organisations or individuals, including university-based researchers, high profile advocates for climate change action, non-government organisations, and civil society alliances, unlikely to be in a position to ensure the strategy is implemented.

In order to understand the strengths and limitations of different examples of post-carbon transition planning, the 'Post Carbon Pathways' review compared the goals, assumptions and priorities of the selected post-carbon transition strategies using a meta-analytical framework. The framework included: emissions reduction and energy related targets and timelines; technology and innovation; economics and finance; social equity; governance; and social and political change. This article summarises findings from the review, in particular the key areas of commonality and variance between strategies, and areas identified as ripe for further analysis.

2. Conceptual and theoretical context

2.1. Understanding the scale and speed of actions required to avoid runaway climate change

The necessity and urgency of a unified, global response to climate change has been consistently identified within academic and policy literature (see, for example, Rockström et al., 2009; Rogelj et al., 2011; UN, 1992). The most prudent transition approaches emphasise the need to maintain the Earth's climate within the boundaries of the Holocene conditions that have sustained human life over the last 10,000 years (Hansen et al., 2008). This is likely to require a rapid reduction of atmospheric CO_2 concentrations to below 350 parts per million (ppm) (Ibid.). Recent comprehensive reviews of the actions needed to achieve the less ambitious – and therefore less prudent – 2 °C target, agreed by the United Nations Framework Convention on Climate Change (UNFCCC) conference in Cancun in 2010, reinforce the need for global CO_2 equivalent (CO_2e) emissions to peak before 2020 (Rogelj et al., 2011) (see also Höhne et al., 2011, 2012; UNEP, 2010b, 2011). Yet, analyses of existing climate change policies from national governments around the world continue to reflect a growing 'emissions gap' between the greenhouse gas emissions reductions currently committed to and the level scientifically correlated to stabilisation of the global climate, within the 'guard rail' of 2 °C (den Elzen et al., 2011; Höhne et al., 2012; Kartha and Erickson, 2011; Rogelj et al., 2011; UNEP, 2010b, 2011). Concern about the 'emissions gap' and a lack of progress made through formal international negotiations under the UNFCCC has led commentators to highlight the importance of leadership from national governments,

[2] The full report from this review, entitled Post Carbon Pathways: Reviewing post carbon economy transition strategies, can be downloaded from: http://www.sustainable.unimelb.edu.au/content/pages/post-carbon-pathways.

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as well as non-government actors to undertake emissions reduction initiatives and drive the necessary transitions (see, for example, Blok et al., 2012).

2.2. How do sustainability transitions occur?

The 'Post Carbon Pathways' review adopted the broad characterisation of transitions as long-term, co-evolutionary, multi-actor processes that require multiple changes in socio-technical configurations, involve a large variety of social groups, and represent radical shifts in scope from one configuration to another (Grin, Rotmans and Schot (2010) as cited in Verbong and Loorbach, 2012, p. 7). Understanding how post-carbon transitions could occur (at different scales) is complex, yet in the context of the growing global 'emissions gap' it is also increasingly urgent. The emergence of broader sustainability transitions theory has been driven by exactly this need for analysis of 'major, system-wide changes that are likely to involve breakthrough technologies and possibly fundamental changes in social aims, institutions, industrial structures and demand' (van den Bergh et al., 2011, p. 7). In the last decade, a set of interrelated approaches within transitions theory has developed drawing particularly on insights from evolutionary economics, innovation and complex systems theories (Cooke, 2011; Markard et al., 2012; van den Bergh et al., 2011; Verbong and Loorbach, 2012; WBGU, 2011, p. 83) to help analyse and explain the processes by which transitions occur. Approaches such as the multi-level perspective (MLP), explained briefly here, are especially helpful for contextualising transition theories underlying strategies analysed in the 'Post Carbon Pathways' review.

The MLP features three levels: (i) the *landscape* level which consists of slow-changing external factors; (ii) the *regime* level which accounts for stability of existing technological development and occurrence trajectories; and (iii) the micro-level of *niches* which accounts for the generation and development of radical innovations. Within this approach, changes at the regime level are triggered by increasing pressure from the social context (landscape) on the dominant actors (regime) or by upcoming, rivalling socio-technical configurations (niches). Transitions result from the co-evolutionary interplay between the processes functioning at the different levels. As Geels confirmed: 'the nested character of these levels, means that regimes are embedded within landscapes and niches within regimes' (Geels, 2002, p. 1261). 'This 'multi-level' perspective suggests that socio-technical development path transitions occur as the result of alignments between changes in each of these three levels (niches, regimes and landscapes), shifting pressures on the regimes and adaptations to these pressures' (Geels and Schot (2007) as cited in Burch, 2010, p. 292). Within the MLP perspective, the 'Post Carbon Pathways' review focuses on strategic change at the regime level in response to the need to address climate change at the landscape level.

Contributions to sustainability transitions theory continue to grapple with the enormity of the challenge of enacting post-carbon transitions, which is clarified by comparison to historical leaps of civilisation such as the Neolithic and Industrial Revolutions (WBGU, 2011, p. 84). As Fouquet (2010) and Solomon and Krishna (2011) conclude in their recent analyses of historical energy transitions, large-scale societal transitions are particularly difficult to guide and generally unfold slowly. Yet evolutionary transitions will be inadequate unless strategically accelerated. The role of informed, forward-looking policy-making to shape large-scale transitions (WBGU, 2011) and "decisive interventions from state and non-state actors" in order to overcome the inertia and lock-in that characterises prevailing socio-technical systems (Markard et al., 2012) will be particularly important.

2.3. The importance of plausible, integrated transition visions

Previous empirical analyses comparing large-scale post-carbon transition strategies have focused on national policy pledges (see, for example, Climate Action Tracker, ND), technological or economic aspects of transitions (see Elliston et al. (2012) and Jacobson and Delucchi (2011) for comparisons of studies of large-scale energy sector transitions). It is, however, increasingly accepted that 'transformation will be as much a matter of social as technical innovation' (Westley et al., 2011, p. 776), and the need to secure and sustain broad social and political support is the greatest obstacle to taking the actions needed to drive a rapid and effective transition to a post-carbon economy (WBGU, 2011).

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As Elliston et al. (2012) point out, of the numerous published studies describing one or more scenarios for individual countries, regions, or the world as a whole to meet 80–100 per cent of energy demand from renewable energy, few include specific transition pathways and methodologies vary significantly between them. Their value lies, nevertheless, in 'showing that aggressive reduction in fossil fuel use is possible and provid[ing] a vision of how the future energy system might look' (Elliston et al., 2012, p. 606). The power of presenting positive visions, and steps to get there, is a common theme in social change literature more broadly (see, for example, Wright, 2010) and the role of transition visions and scenario creation has been identified as a key instrument with a role to play in stimulating, guiding and accelerating initial, pre-development phases of transitions (STRN, 2010).

Several of the non-government transition strategies analysed provide demonstrations of the potential of open-source policy making and innovation, drawing on the energy and creativity of a diverse coalition of volunteer researchers, writers and designers. Most importantly, they can reframe political discourse by breaking open the assumption that alternative, scaled-up energy pathways and systems are simply not feasible. As Westley et al. (2011, pp. 771–772) note, innovative networks of activists and academics can catalyse public participation to levels which push policy debates towards experimentation with alternatives and bridge the gap between intention and action. Such approaches highlight the important role of 'shadow networks' referring to 'informal networks that work both outside and within the dominant system to develop alternatives that can potentially replace the dominant regime if and when the right opportunity occurs' (Ibid., p. 771).

Given the increasing global 'emissions gap' between scientifically prudent emissions reduction targets and those committed to by national authorities, and the complexity involved in creating integrated and effective emissions reduction plans, it is critical that lessons from ambitious or influential transition strategies, from a variety of actors, be understood and captured.

3. Method

The 'Post Carbon Pathways' review involved three key steps: (1) identification of a sample set of eighteen large-scale post-carbon transition strategies; (2) development of concise summaries according to a common analytical template; and (3) comparative analysis between the strategy summaries to extract key commonalities, differences and overarching lessons.

3.1. Identifying post-carbon transition strategies

First, a non-exhaustive sample of eighteen post-carbon transition strategies was selected after a desktop review of documents including policy papers, roadmaps, action plans, books, detailed reports and journal articles, published between June 2008 and December 2011. The following seven criteria were used to inform selection:

1. Published: publicly accessible through print or web.
2. Purposeful: intended to stimulate and inform action.
3. Large-scale: national or regional.
4. Explicit: advocating actions to achieve quantitative goals and (usually) costed.
5. Scalable: having potential to be scaled-up or accelerated.
6. Comprehensive: addressing all greenhouse gas-emitting sectors, or energy use (as energy is a principal source of greenhouse gases (Verbong and Loorbach, 2012, p. 4).
7. Ambitious: goals and targets calibrated at a scale and speed broadly consistent with outcomes needed to prevent runaway climate change.

The nine strategies from non-government sources and nine from government sources are listed in Tables 1 and 2 respectively. The selected strategies have been classified according to whether they focus on: (i) the global economy as a whole; (ii) the global energy sector only; (iii) a multi-country, regional economy (European Union); (iv) a national economy; (v) a national energy sector only; and (vi) a large, sub-national economy (California, USA).

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Table 1
Post-carbon economy transition strategies – non-government sources.

Non-government post-carbon economy transition strategies			
Scope	Strategy or plan	Source	Link and citation
Global – all sectors	World in Transition: A Social Contract for Sustainability	German Advisory Council on Global Change	http://www.wbgu.de/en/flagship-reports/fr-2011-a-social-contract/ (WBGU, 2011)
	World on the Edge: How to Prevent Environmental and Economic Collapse	Lester R. Brown, Earth Policy Institute	http://www.earth-policy.org/books/wote (Brown, 2011)
	Our Choice: A Plan to Solve the Climate Crisis	Al Gore	http://ourchoicethebook.com/ (Gore, 2009)
	One Degree War Plan	Paul Gilding and Jorgen Randers	http://www.emeraldinsight.com/journals.htm?articleid=1860356 (Randers and Gilding, 2010)
Global – energy sector only	Powering a Green Planet: A Path to Sustainable Energy by 2030	Mark Z. Jacobson and Mark A. Delucchi	http://www.scientificamerican.com/article.cfm?id=a-path-to-sustainable-energy-by-2030 (Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2009, 2011)
	The Energy Report: 100% Renewable Energy by 2050	WWF International	http://wwf.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/renewable_energy/sustainable_energy_report/ (WWF, 2011)
National – all sectors	Zero Carbon Britain 2030	Centre for Alternative Technology	http://zerocarbonbritain.org/ (Kemp and Wexler, 2010)
	Low Carbon Growth Plan for Australia	Climate Works Australia	http://www.climateworksaustralia.org/Low%20Carbon%20Growth%20Plan.pdf (ClimateWorks Australia, 2010)
National – energy sector only	Zero Carbon Australia 2020 – Stationary Energy Plan	Beyond Zero Emissions and Energy Research Institute, The University of Melbourne	http://beyondzeroemissions.org/zero-carbon-australia-2020 (Wright and Hearps, 2010)

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Table 2
Post-carbon economy transition strategies – government sources.

Government post-carbon economy transition strategies			
Scope	Strategy or plan	Source	Link
Regional – all sectors	A Roadmap for Moving to a Competitive Low Carbon Economy in 2050	European Commission	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF (European Commission, 2011)
National – all sectors	The Carbon Plan: Delivering our Low Carbon Future	Government of the United Kingdom	http://www.decc.gov.uk/en/content/cms/tackling/carbon_plan/carbon_plan.aspx (HM Government, 2011)
	National Strategy for Green Growth	Government of the Republic of Korea	http://www.greengrowth.go.kr/english/en_main/index.do (Presidential Committee on Green Growth, ND; UNEP, 2010a)
	China's 12th Five-Year Plan *and* White Paper of China's Policies and Actions in Responding to Climate Change	Government of the People's Republic of China	http://cbi.typepad.com/china_direct/2011/05/chinas-twelfth-five-new-plan-the-full-english-version.html and http://www.gov.cn/english/official/2011-11/22/content_2000272.htm (Government of the People's Republic of China, 2011a,b)
	National Action Plan on Climate Change *and* Low Carbon Strategies for Inclusive Growth: An Interim Report	Government of India	http://pmindia.nic.in/Pg01-52.pdf and http://planningcommission.nic.in/reports/genrep/Inter_Exp.pdf (Government of India, 2008; 2011)
	Securing a Clean Energy Future	Government of Australia	http://www.cleanenergyfuture.gov.au/clean-energy-future/our-plan/ (Commonwealth Government of Australia, 2011)
National – energy sector only	Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply	Government of Germany	http://www.bmu.de/files/english/pdf/application/pdf/energiekonzept_bundesregierung_en.pdf (Government of Germany, 2010)
	Our Future Energy	Government of Denmark	http://www.ens.dk/Documents/Netboghandel%20-%20publikationer/2011/our_future_energy_%20web.pdf (The Danish Government, 2011)
Sub-national – all sectors	Climate Change Scoping Plan *and* California's Clean Energy Future	Government of California	http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm and http://www.cacleanenergyfuture.org/ (California Air Resources Board, 2008; State of California, 2010)

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3.2. Framework for analysis of selected post-carbon economy transition strategies

The strategies vary significantly in terms of approach, methodology and the level of detail provided about different aspects of the transition. In order to better understand these differences, each of the selected strategies was analysed according to a framework of questions. The analytical framework included first, determining the *source, overall aims and scope* – both jurisdictional and sectoral – of the strategy. Second, any *greenhouse gas emission reduction or energy-related targets and timelines* specified within the strategy were noted. Third, the strategies were analysed for any assumptions or prioritised actions with respect to broad fields of: *technology and innovation* (including the types of technologies promoted, assumptions about expected technological development and actions to drive technological innovation); *economics and finance* (including assumptions about the effectiveness of market-based, regulatory and direct investment mechanisms, trends in consumer demand and energy efficiency, the desirability of redefining and/or reducing current rates of economic growth, and any specified costing or funding models); *social equity* (including any references to questions of intra- and inter-generational equity); *governance* (including broad assumptions about institutional responsibility for different actions); and *social and political change* (including key assumptions about the scale and speed of societal and political transformations required to achieve the aims of the strategy, and mechanisms by which they could unfold).

3.3. Comparative analysis

Once summary notes had been completed for each strategy using the analytical framework described above, results under each of the fields were compared across different strategies in order to extract key commonalities, differences and overarching lessons.

4. Results and discussion

Comparative analysis of the key features of the post-carbon economy transition strategies considered in this report leads to the following main lessons and implications.

4.1. Source, aims and scope

As shown in Tables 1 and 2 above, the selected transition plans have some important basic differences. These include whether or not they were produced by government or non-government actors, the geographic and jurisdictional scales of focus, and the greenhouse gas emitting sectors that were included as part of the strategy. In addition to these basic differences of source, aims and scope, the plans varied in terms of the level of detail included.

4.2. Emissions reduction, energy demand and energy supply targets

The most ambitious of the selected strategies, all produced by non-government sources, aim for emissions reduction and renewable energy targets of 80 to 100 per cent within timeframes ranging from 10 to 20 years. Six strategies fit into this more ambitious grouping, including: (Brown, 2011; Gore, 2009; Jacobson and Delucchi, 2009; Kemp and Wexler, 2010; Randers and Gilding, 2010; Wright and Hearps, 2010). These strategies emphasise the importance of calibrating targets according to the requirements for limiting global temperature rise to below 2 °C above pre-industrial levels. Less ambitious non-government and industrialised government strategies aim for emissions reduction and renewable energy targets in the range of 5–40 per cent within 10–20 years, with 80–100 per cent targets more common for 2050. These include the following nine strategies analysed for the review: (California Air Resources Board, 2008; ClimateWorks Australia, 2010; Commonwealth Government of Australia, 2011; European Commission, 2011; Government of Germany, 2010; HM Government, 2011; The Danish Government, 2011; WBGU, 2011; WWF, 2011). The three remaining strategies produced by the South Korean (UNEP, 2010a), Chinese (Government of the People's Republic of China, 2011a) and Indian governments (Government of India, 2008) were the least ambitious in terms of emissions

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and energy targets with each including goals for reducing emissions intensity (emissions per unit of GDP) or limiting projected emissions growth, in the period to 2020.

The different targets and timelines demonstrate a crucial difference between transition strategies that advocate a relatively slow and incremental approach to emissions reductions compared to those that advocate more rapid and transformational change.

4.3. Technology and innovation assumptions and priorities

Overall, the analysis of the selected strategies clearly demonstrates that technological barriers are not the major obstacles to the transition to a post-carbon economy. The technological changes commonly highlighted within the strategies fit under three main headings: (1) reductions in energy consumption and improvements in energy efficiency; (2) replacement of fossil fuels by renewable energy; and (3) drawdown and sequestration of carbon into sustainable carbon sinks.

4.3.1. Reducing energy consumption and improving energy efficiency

All of the strategies analysed see a strong role for energy efficiency. Specific solutions associated with reducing energy consumption and increasing energy efficiency are typically separated into actions by sector. Common technological priorities across different strategies in relation to the buildings sector include: retrofitting and insulating existing buildings; a wide roll-out of passive solar, combined heat and power and decentralised heating and cooling systems; and improving efficiency of all heating, cooling, lighting and appliances. In the industry sector, common priorities include: upgrading inefficient industrial processes; reducing fugitive methane emissions from mining; and improving recycling and abatement technologies for non-CO_2 emissions. For transport, common priorities include: reducing carbon intensity of transportation fuels; replacing fossil fuel cars with electric and plug-in hybrid vehicles; upgrading inefficient electric motors; expanding the use of second-generation biofuels (e.g. algal biodiesel and lingo-cellulosic ethanol) and hydrogen (from renewable electricity) to be used for some shipping.

4.3.2. Replacing fossil fuels with renewable energy

Despite different targets and timescales, each of the strategies also emphasised the need to promote a rapid shift from fossil fuels to renewable energy, with technological priorities across different strategies commonly including the design and construction of interconnected 'smart' grids and the significant expansion of innovation, investment and deployment in the following energy sources: solar (concentrated and photovoltaic (PV)); wind (on- and off-shore); wave and tidal; hydroelectricity; geothermal (directly to heat buildings and at high temperatures for electricity generation); bioenergy (traditional biomass; sustainable residues and waste; sustainable energy crops; and sustainable algaes); the use of spare wind, water and solar energy to produce electrolytic hydrogen; and liquefied hydrogen combustion for aircraft.

4.3.3. Reducing land use emissions and sequestering carbon

Analysis across the range of transition strategies which included land use emissions within scope, revealed the following common technological priorities for reducing land use emissions and improving the role of land use in carbon sequestration: reducing cropland soil emissions through reducing tillage, improving fertiliser and nutrient management, and restoring degraded farmland; cropland carbon sequestration; improving pasture and grassland management through optimising grazing intensity, expanding planting of deep-rooted perennial grasses, and improving fire management; reducing livestock emissions through active livestock feeding, anti-methanogenic treatments, and improving manure management; and bio-gasification of organic manure through capture or burning of agricultural methane. Other policy and behaviour focused priorities were also common across strategies, such as ending and reversing deforestation, reducing livestock production and consumption and increasing local food production and distribution.

There are important differences between strategies in the assumptions made about the potential speed and scale of innovation and commercialisation of different technologies. This is especially clear in relation to technologies for reducing emissions from non-renewable and fossil fuel energy sources.

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Most strategies either directly prioritise or include a possible role for carbon capture and storage (CCS) as a way of continuing to use fossil fuels. Non-government strategies are more likely to rule out or dismiss CCS for being neither technologically nor financially viable in the near future (Brown, 2011; Jacobson and Delucchi, 2009; Kemp and Wexler, 2010; The Danish Government, 2011; Wright and Hearps, 2010; WWF, 2011). Similarly, while most non-government-authored strategies do not support nuclear energy, some government-authored strategies continue to assume a transitional, ongoing or expanded role for nuclear energy (see Table 3).

This difference also tends to reflect a greater reliance on technological solutions in government authored strategies. The non government authored strategies reviewed in this study tend to place greater emphasis on the need for significant reductions in the demand for energy and resources if emissions reductions are to be achieved at sufficient speed and scale.

4.4. Economic policy and financial implications and priorities

The analysis of the selected strategies clearly demonstrates that the financial costs of economic and industry restructuring represent significant but not insurmountable obstacles to the transition to a post-carbon economy. Our analysis compared strategies based on (1) the estimated costs of transition and assumptions embedded in cost calculations, (2) economic policy priorities, relating to how to drive and fund the transition, and (3) whether or not current assumptions about the nature and level of economic growth were raised.

4.4.1. Costs of the transition

The majority of strategies emphasise the importance of 'cost effectiveness' in determining priority actions. They contain a wide variety of approaches to calculating and reporting the financial costs of post-carbon economy transition policies. There is considerable diversity in the timeframes over which costs and benefits are considered, as well as in assumptions about future trends, such as fossil fuel resource prices and availability, and cost trajectories for renewable energy technology and deployment. The United Kingdom (UK) Government's Carbon Plan (HM Government, 2011), for example, contrasts the 'static' cost effectiveness of particular technologies (based on short-term conditions, such as the current carbon price) with the 'dynamic' cost effectiveness' (considering actions required to meet longer term targets). Taking a longer term view requires higher upfront investments, but can optimise longer term impacts and savings. Strategies also differ in the way cost estimates are reported (for example, as the total amount to implement the actions outlined, an amount per year over a set period of time, a proportion of GDP, or an amount of investment additional to current levels) and who they are attributed to (for example, the overall cost to society, the amount of government spending required, the estimated private investment required, or unattributed investment). Many strategies also note the importance of strengthening understanding of the financial, economic and social costs of failing to take action to reduce emissions, and of the multiple employment, health and social equity co-benefits of a swift transition to a post-carbon economy.

Noting the wide variation in scope and costing assumptions, ballpark estimates of the costs of actions required to rapidly decarbonise the global economy range from US$200–5000 billion p.a. over different timeframes.[3] Costs for Europe are estimated at €270 billion p.a. over 40 years (1.5 per cent of EU GDP p.a. above overall 2009 investment levels) (European Commission, 2011). Indicative national level costings, also noting significant differences in the scale and speed of proposed actions and costing assumptions, include: £50 billion p.a. to implement the *Zero Carbon Britain 2030* study (Kemp and Wexler, 2010) or an average cost of between 0.4 and 0.6 per cent of UK GDP p.a. for the UK Government policy (HM Government, 2011); AUD 37 billion p.a. over ten years or approximately 3 per cent of Australian GDP to implement the *Zero Carbon Australia 2020 – Stationary Energy Plan* (Wright and Hearps, 2010); €20 billion p.a. over 40 years to implement Germany's *Energy Concept* (Government

[3] This range includes the following examples: US$200 billion p.a. (Brown, 2011); US$200 to US$1000 billion p.a. to 2030 (WBGU, 2011); €1000 billion p.a. (WWF, 2011); US$2500 billion p.a. (Randers and Gilding, 2010); and US$100 trillion over twenty years (Jacobson and Delucchi, 2009).

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Table 3
Post-carbon economy transition strategies: summary of key features.

Strategy or plan	Energy and emissions targets	Energy supply assumptions and priorities	Significant questioning of current economic paradigm	Approximate cost of transition policies
World in Transition (WBGU, 2011)	Decarbonise global energy system by 2050	Renewables; no nuclear; possibly CCS	Yes	Additional net investment US$200 and $1000 billion p.a. by 2030
World on the Edge (Brown, 2011)	Cut global CO_2 emissions by 80% by 2020 (on 2006 levels)	Renewables; no nuclear or CCS	Yes	Net cost US $200 billion p.a.
Our Choice (Gore, 2009)	Rapid reduction to 350 ppm atmospheric CO_2 concentration	Renewables, nuclear, CCS all considered	Yes	Does not include detailed costings
One Degree War Plan (Randers and Gilding, 2010)	Cut global GHG emissions to zero over 15 years; negative emissions for rest of century	Renewables. Low possibility of nuclear and CCS	Yes	Carbon tax expected to generate US$2500 billion p.a. by year 5 to spend on transition
Powering a Green Planet (Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2009, 2011)	Switch global energy system to 100% renewable energy (wind, water, solar) by 2030	100% renewables: wind, water and solar sources only	No	Ballpark figure of US $100 trillion over 20 years in gross investment to construct global renewable energy systems. BAU will cost approx US$10 trillion (not inc. mounting social costs)
The Energy Report (WWF, 2011)	Peak and decline global GHG emissions within five years, reduce by 80% by 2050 (on 1990 levels); 100% renewable energy by 2050	Renewables; no nuclear or CCS; 5% fossil fuels	No	Total cost of achieving targets approx €1 trillion p.a. Investment expected to have paid itself off by around 2040 at latest
Zero Carbon Britain 2030 (Kemp and Wexler, 2010)	Reduce net UK GHG emissions to zero by 2030	Renewables; no CCS; no *new* nuclear	Yes	Ballpark figure of £50 billion p.a. required for initial investment programme
Climate Works Low Carbon Growth Plan for Australia (ClimateWorks Australia, 2010)	Reduce Australian GHG emissions by 25% by 2020	Fossil fuels; CCS; renewables	No	AU$1.8 billion per year. Strong emphasis on net savings to business
Zero Carbon Australia Stationary Energy Plan (Wright and Hearps, 2010)	Reduce net Australian GHG emissions to zero by 2020; 100% of stationary energy from renewables by 2020	100% renewables	No	AU$37 billion p.a. for ten-year period, or approx 3% of Australian GDP. Net present costs over longer time period (2010–40) roughly equiv to BAU (not inc. transport savings)
European Commission: Roadmap 2050 (European Commission, 2011)	Reduce EU GHG emissions by 20% by 2020 and 80–95% by 2050 (on 1990 levels)	Renewables; CCS; nuclear	No	Approx. €270 billion p.a. over 40 years (approx 1.5% of EU GDP p.a. above 2009 investment levels). Savings between €175–320 billion p.a. (not incl. saving on social costs)

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Table 3 (*Continued*)

Strategy or plan	Energy and emissions targets	Energy supply assumptions and priorities	Significant questioning of current economic paradigm	Approximate cost of transition policies
UK: Carbon Plan (HM Government, 2011)	Reduce UK GHG emissions by 34% by 2020 and 80% by 2050 (on 1990 levels)	Fossil fuel (shift to gas); nuclear; CCS; renewables	No	Total net present cost over lifetime of policies in past carbon budget periods approx £9 billion. Average cost approx 0.4% of UK GDP p.a. in period 2008–22 and 0.6% of UK GDP per year over 2023–27
South Korea: Green Growth Strategy (Presidential Committee on Green Growth, ND; UNEP, 2010a)	Reduce Korean GHG emissions by 30% below projected 2020 levels (equivalent to 4% reduction on 2005 levels)	Fossil fuels; nuclear; renewables	No	Total investment announced as part of Five-Year Plan (2009–13) US$83.6 billion
China: 12th Five-Year Plan & Climate Change White Paper (Government of the People's Republic of China, 2011a,b)	Reduce Chinese CO_2 emissions per unit of GDP by 40–45% by 2020 (on 2005 levels)	Fossil fuels (incl. unconventional oil and gas); CCS; nuclear; renewables	No	Total investment (both public and private) in 'new energy' of approx RMB 5 trillion (US$760 billion) over next 10 years
India: National Action Plan & Low Carbon Growth Report (Government of India, 2008, 2011)	Reduce India's emissions intensity of GDP by 20–25% by 2020 (on 2005 levels)	Fossil fuels; possibly CCS; nuclear; renewables	No	Does not include detailed costings
Australia: Clean Energy Future (Commonwealth Government of Australia, 2011)	Reduce Australian GHG emissions by 5% by 2020 and 80% by 2050 (on 2000 levels)	Fossil fuels; CCS; renewables	No	Carbon price and related measures to raise approx AUD$25.5 billion in the period 2011–15. Further $3.9 billion public funds to augment
Germany: Energy Concept (Government of Germany, 2010)	Reduce German GHG emissions by 40% by 2020 and at least 80% by 2050 (on 1990 levels)	Renewables; possibly CCS; phase-out nuclear	No	Additional investment €20 billion p.a., offset by energy cost savings
Denmark: Our Future Energy (The Danish Government, 2011)	100% renewable energy in all Danish energy supply by 2050	100% renewables	No	Cost to 2020 approx DKK 5.6 billion (US$952 million). Immediate net costs of <0.25% GDP in 2020. Average additional costs to Danish households approx DKK 1700 (US$289) in 2020
California: Scoping Plan & Clean Energy Future Plan (California Air Resources Board, 2008; State of California, 2010)	Reduce GHG emissions to 1990 levels by 2020 and 80% of 1990 levels by 2050; 33% of electricity from renewable energy by 2020	Fossil fuels; possibly CCS; renewables	No	Ongoing costs approx US$ 36 million p.a. Benefits by 2020 (compared to BAU) inc. increases in economic production of US$33 billion and overall gross state product of US$7 billion

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of Germany, 2010); $US 83 billion over five years for South Korea's policies (UNEP, 2010a); and the equivalent of $US 952 million in the period to 2020, or net costs of 0.25 per cent of Danish GDP, for Denmark's *Our Future Energy* policy.

4.4.2. Economic policy priorities – how to drive and fund the transition

All of the strategies considered in the 'Post Carbon Pathways' review include some mix of market-based and regulatory policies. Most also include a range of more direct government incentives and actions to improve energy efficiency and shift energy production and consumption away from fossil fuels to renewable energy. Strategies for raising the required level of funding include: global, national or regional carbon price schemes; collection of a small 'Tobin' tax on international financial transactions; redirection of current taxation revenue; tax incentives, low interest loans and loan guarantees to encourage investment in renewable energy enterprises and R&D; a variety of national and local level 'green bond' schemes; and, for developing economies, financial assistance from developed countries.

The strategies analysed generally strongly support both 'cap and trade' and carbon tax policies for setting a price on carbon. A number of strategies that are more focused on science-based time frames for transition note that a rapid increase in the global carbon price (towards US$100–US$200 a tonne) is likely to be required if the price of carbon is to be the primary mechanism driving the transition to a post-carbon economy.

The ongoing downwards pressure on global carbon prices over the period 2011–2013 suggests that reliance on market based mechanisms alone is most unlikely to provide a sufficient basis for rapid emissions reductions. Strategies arguing for the most rapid rates of renewable energy deployment (see, for example, Jacobson and Delucchi, 2009; The Danish Government, 2011; Wright and Hearps, 2010) in fact tend to prioritise non-market legislative and regulatory measures to drive a rapid transition from fossil fuels to renewable energy. These include binding renewable energy targets; feed in tariffs; elimination of fossil fuel subsidies and the enforced closure of fossil fuel mining, export and power generation activities.

4.4.3. Rethinking assumptions about economic growth

The strategies analysed differ markedly in their assumptions about the possibility and desirability of maintaining current material consumption levels and ensuring continuing economic growth. Five non-government strategies – (Brown, 2011; Gore, 2009; Kemp and Wexler, 2010; Randers and Gilding, 2010; WBGU, 2011) – included an emphasis on the need to rethink and reframe current assumptions about the nature and level of economic growth, and to rapidly explore alternatives to current economic paradigms and policy settings. Of the remaining non-government strategies, two only considered levels of emissions reductions that would not cause significant changes to, or limitation of, material consumption – (ClimateWorks Australia, 2010; WWF, 2011) – and two did not explicitly discuss the implications for economic growth or material consumption (Jacobson and Delucchi, 2009; Wright and Hearps, 2010). None of the government authored post-carbon strategies explicitly discuss the need to question their increasingly untenable assumptions in relation to unconstrained in the consumption of energy and resources. Strategies concerned with developing country economies, such as China, India and South Korea, all assume an important role for continued economic growth in helping to meet human development goals. These strategies highlight concepts of 'green growth' and 'low carbon growth', and emphasise the need for economic development to be linked to, or driven by, development in 'low carbon' industries and programmes.

Table 3 on the following page summarises key targets and technology, economic and financial elements of the strategies.

4.5. Social equity implications and priorities

The surprisingly limited discussion of transnational and intergenerational equity or future discounting assumptions and trade-offs suggests a need for more explicit discussion of ethical frameworks for understanding how a socially just approach to climate change can most effectively be translated into robust policy interventions.

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The primary concern of many of the government-led strategies analysed is generally limited to addressing social equity concerns at the national rather than international level (e.g. Commonwealth Government of Australia, 2011; Government of India, 2011; HM Government, 2011; Presidential Committee on Green Growth, ND). These national strategies commonly note the potentially severe impacts on disadvantaged and low income communities and individuals of failing to take timely and effective action to reduce the risks of runaway climate change, and describe policy mechanisms aimed at ensuring a fair distribution of costs of the transition across different social groups.

4.6. Governance implications and priorities

The strategies analysed broadly agree that a rapid transition to a post-carbon economy is likely to require strong leadership by national governments in setting and achieving clear long-term emissions reduction targets, combined with strengthened grassroots mobilisation, active support from the private sector, and enhanced global cooperation. Several strategies emphasise the unprecedented scale of action required and argue for strengthened global institutions and cooperation (e.g. Brown, 2011; Gore, 2009; Randers and Gilding, 2010; WBGU, 2011; WWF, 2011).

Only one of the strategies analysed – the WBGU's *World in Transition* report – argues for a radical shift to a new 'global social contract' which refers to 'the necessity of humankind taking collective responsibility for the avoidance of dangerous climate change and other dangers to the planet' (WBGU, 2011, p. 8), and includes substantial detail about the shifts required in current governance arrangements. Promising options for strengthening global cooperation raised in the WBGU (2011) report include: continuing to work towards a global climate change action compact committing all nations to an internationally verifiable decarbonisation road map and a shared approach to carbon pricing; the development of sub-global, regional alliances and collaborations involving nation states and sub-national regions, provinces and cities; the design and construction of international smart electricity grids and networks; a strengthened role for international governance institutions, such as the International Energy Agency and the International Renewable Energy Agency; and the embedding of renewable energy investment priorities at the heart of all international aid and development programmes.

While most strategies note an important role for government, for example in legislating national climate protection targets, encouraging and driving investment in key infrastructure and green economy projects (e.g. smart grids, high-speed rail and electric vehicle recharging stations), a number of strategies also emphasise the importance of encouraging distributed and decentralised energy systems and reinvigorating local economies (e.g. Kemp and Wexler, 2010; Presidential Committee on Green Growth, ND).

4.7. Political and social change assumptions and priorities

Most strategies analysed ultimately supported the notion that the need to secure and sustain broad social and political support is the greatest obstacle to taking the actions needed to drive a rapid and effective transition to a post-carbon economy. While many strategies acknowledge this, the analysis revealed a lack of detailed steps for achieving broad social and political support and for driving transformational social change. This frequently reflects an implicit assumption of a rational policy-making process in which the objective merits of the strategy provide a sufficient basis for driving change.

Table 4 summarises the assumptions and priorities in relation to achieving social and political change contained within the selected post-carbon transition strategies. The most common assumptions in relation to transformational change within the selected strategies relate to the need for visionary political leadership combined with broad community mobilisation. Many also highlight the potential for one or more dramatic 'tipping point' events, whether directly arising from climate change or not, to trigger a swift, large-scale shift in political values and responses (e.g. Brown, 2011; Randers and Gilding, 2010).

Of all the strategies presented in this report, the WBGU's *World in Transition* report (2011) presents the most comprehensive assessment of the social change dynamics that could underpin broad public acceptance and support for transition. It emphasises: knowledge-based, shared visions and the

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Table 4
Post-carbon economy transition strategies: social and political change assumptions and priorities.

Strategy or plan	Social and political change assumptions and priorities
World in Transition (WBGU, 2011)	Key conditions for creating social dynamics for change: knowledge-based, shared visions of desirable future; strong and effective change agents and champions; social and economic 'shocks; proactive state and supportive global governance structures. Strategic opportunities for overcoming barriers to transformational change: rapid advances in low carbon technology innovation; recognition that required investments are viable when compared with greater costs of inaction; changing values towards sustainability; global knowledge networks; and recognition of co-benefits of transformational change.
World on the Edge (Brown, 2011)	Transition requires decarbonisation at 'wartime speed'. Three social change models: • Pearl Harbor: Dramatic event leads to fundamental change (too risky?) • Berlin Wall: Social tipping point reached after gradual change in thinking and attitudes (too slow?) • Sandwich: Grassroots movement strongly supported by political leadership (preferred).
Our Choice (Gore, 2009)	Overcoming social, political and attitudinal barriers to climate action requires visionary leadership combined with broad community mobilisation. Need to hold self-interested corporations to account and ensure higher standards in media.
One Degree War Plan (Randers and Gilding, 2010)	Prevention of catastrophic climate change requires broad support for comprehensive and integrated action at scale and speed comparable to Second World War mobilisation. At some point (before 2020?) one or more critical ecological, economic or social tipping point events likely to occur, leading to shift in public support for action required.
Powering a Green Planet (Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2009, 2011)	Obstacles to implementation of 100% global renewable energy system by 2030 'primarily social and political, not technological'; need for strong leadership to avoid dominance of industry-preferred technologies.
The Energy Report (WWF, 2011)	Reduction in energy demand from energy efficiency savings, rather than restrictions on human activities; emphasis on human ingenuity, technological innovation and behaviour change as key drivers of transition.
Zero Carbon Britain 2030 (Kemp and Wexler, 2010)	Notes dynamic nature of politics and role of sudden, unexpected events in driving dramatic political shifts; importance of having plans in place to avoid predictable, but uncertain, shocks (e.g. peak oil). Importance of behaviour change plus promotion of wider societal dialogue on values, structures and processes that have led to overconsumption, climate change and resource depletion.
Climate Works Low Carbon Growth Plan for Australia (ClimateWorks Australia, 2010)	Focus on winning support from key industry sectors as a basis for winning broader social and political support.
Zero Carbon Australia Stationary Energy Plan (Wright and Hearps, 2010)	Need for 'decisive leadership' from government, business, academia and the wider community to implement the plan. Focus on contributing to settling debate on technical feasibility of 100% renewable energy in Australia to enable social and political changes to occur.
European Commission: Roadmap 2050 (European Commission, 2011)	Political and social change factors not covered in detail, although notes importance of policy innovation, behaviour change and public education programmes.
UK: Carbon Plan (HM Government, 2011)	Importance of UK Government, industry and citizens to be 'pulling in the same direction' in order to achieve low carbon transition.
South Korea: Green Growth Strategy (Presidential Committee on Green Growth, ND; UNEP, 2010a)	Emphasis on education and raising public awareness about need for lifestyle change needed to support green growth.
China: 12th Five-Year Plan & Climate Change White Paper (Government of the People's Republic of China, 2011a,b)	Underlying assumption of strong and ongoing role for co-ordinated government planning and intervention, consistent with overall Chinese economic and political governance arrangements.
India: National Action Plan & Low Carbon Growth Report (Government of India, 2008, 2011)	Political and social change factors not covered in plans considered. Interim report notes need for the final report to include discussion of barriers to implementation or adoption by people and firms of Indian climate change policies.
Australia: Clean Energy Future (Commonwealth Government of Australia, 2011)	Carbon price as central driver of change. Strong emphasis on limited impact of policy measures on Australian economy and lifestyles.

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Table 4 (*Continued*)

Strategy or plan	Social and political change assumptions and priorities
Germany: Energy Concept (Government of Germany, 2010)	Importance of public understanding and support for transition to ensure its success. Measures include provision of comprehensible information, transparent decision making and opportunities for public dialogue.
Denmark: Our Future Energy (The Danish Government, 2011)	Elements contributing to social and political acceptance of Denmark's energy transition not covered in the plan. Assumes strong ongoing role for government in encouraging innovation and community education.
California: Scoping Plan & Clean Energy Future Plan (California Air Resources Board, 2008; State of California, 2010)	Active public participation essential. Emphasis on role for market forces and growing environmental awareness to shift individual choices and attitudes. Calls for targeted public outreach, marketing and education programmes.

importance of advocating desirable futures, rather than triggering anxiety; the important role of change agents, social and economic megatrends and 'shocks'; and the need for proactive nation-states and supportive global governance structures (WBGU, 2011, pp. 5–6).

4.8. Priorities for further research

The analysis raises a number of improvements to be prioritised for future transition planning. First, further work is required to broaden and deepen public understanding of the relationship between emissions reductions and global temperatures and to specify the global, national and local emissions reduction, energy consumption, renewable energy and carbon sequestration targets required to significantly reduce the risk of runaway climate change. The wide variety of terms used to communicate emissions reduction and energy targets makes comparison between strategies difficult and is an ongoing barrier to effective communication to broader, non-technical audiences. There is increasing evidence that the 'carbon budgets' approach (as utilised in the UK Government's *Carbon Plan* (HM Government, 2011)) is the most effective and robust methodology for achieving this aim with targets set and monitored on an annual basis (see Anderson and Bows, 2011).

In addition, further research would be valuable to: (i) identify the most effective strategies for encouraging, sharing and deploying large-scale technological and social innovation; (ii) develop robust, transparent methodologies for calculating the net costs of large-scale transition strategies and equitable mechanisms for mobilising the necessary resources; (iii) develop robust frameworks for understanding how a socially just approach to climate change translates into actions at national and international levels; and (iv) clarify the most effective governance strategies for achieving binding and verifiable emissions reduction agreements at global, regional, national and local levels, informed public debate about climate change challenges and solutions, and mobilisation of local community innovation and activism.

Finally, there is a crucial need for further research to identify political, social and cultural change strategies with the potential to drive rapid implementation of the policies needed for a swift transition to a post-carbon economy. As identified earlier in this paper, there is a need to accelerate the rate of transformation rather than waiting for an evolutionary response. To do this, there is a need to further investigate the potential being explored within transitions theory in order to facilitate more dynamic change.

Although this review has focused on large-scale, integrated strategies, the authors are conscious that there are also a wide variety of innovative and influential post-carbon transition strategies that are being developed and implemented at local and regional levels, as well as in specific metropolitan contexts (see Anguelovski and Carmin, 2011; Bulkeley et al., 2011; Romero-Lankao and Dodman, 2011; Rosenzweig et al., 2010) and community-driven emissions reductions initiatives (see, for example, Hopkins, 2008). While they are beyond the scope of this study, they should be the subject of further comparative research and analysis.

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5. Conclusion

This review of eighteen post-carbon transition strategies shows that globally, detailed policy and research initiatives are demonstrating that a rapid transition to a post-carbon economy is technologically and economically feasible. However, the latest climate science shows that the window for effective action is rapidly closing. Strategies to reduce emissions at the required scale and speed will need to be implemented in the next five to ten years if they are to significantly reduce the risk of runaway climate change.

Overall, the 'Post Carbon Pathways' review reveals a crucial difference between those strategies that advocate for a relatively incremental approach to post-carbon transitions – with less ambitious targets and timeframes for emissions reduction or renewable energy transitions – and those that emphasise the need for more rapid and transformational change. This highlights two challenging and increasingly urgent questions. First, for less ambitious plans and strategies (generally government-led): Given that the proposed actions do not match the physical requirements of action needed to prevent runaway climate change, what can be done to bridge this gap? Many of the answers to this first question can be found in the more ambitious non-government authored strategies. However this in turn highlights the importance of a second crucial question: Given that political and social support for the rapid implementation of these proposals remains so challenging: what can be done to bridge this gap?

The selected strategies vary substantially in their assumptions about feasible targets and time frames, technologies and policies to be prioritised. Of the strategies that are more closely aligned to climate science imperatives, common messages include that a fair and swift transition to a sustainable post-carbon economy will require:

- rapid reductions in energy consumption and improvements in energy efficiency;
- rapid replacement of fossil fuels by renewable energy;
- the drawdown and sequestration of carbon into sustainable carbon sinks;
- game-changing investment in social and technological innovation;
- economic policies which recognise the full costs of failing to reduce emissions and of the multiple co-benefits of the transition programme; and
- a significant shift towards economic paradigms and priorities which focus on improving social and ecological wellbeing rather than unconstrained growth in material consumption.

The strategies typically did not go into great detail about how to address social equity or governance aspects of the transition and this is an area for future consideration and development. There is also a lack of detailed game plans within the strategies analysed for mobilising the required level of political leadership and public support for rapid transitions. This remains the most significant gap in post-carbon economy transition strategies. Despite their limitations, however, these integrated strategies provide the essential ingredients for detailed public discussion of specific options, costs, obstacles and priority actions for implementing transition pathways.

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