The economic case for adopting low-carbon trajectories in low-income countries: a test case of the electricity sector

Prachi Seth

Working Paper 359

Results of ODI research presented in preliminary form for discussion and critical comment

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October 30, 2012

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ISBN 978 1 907288 96 8
Working Paper (Print) ISSN 1759 2909
ODI Working Papers (Online) ISSN 1759 2917

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Acronyms

BAU	Business as usual
BTU	British Thermal Unit
CAGR	Compounded Annual Growth Rate
CERs	Certified Emission Reduction
EIA	Energy Information Administration
EU ETS	European Union Emission Trading Scheme
EUR	Estimated Ultimate Recovery
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Giga Joules
GNP	Gross National Product
GW	Giga Watts
KW	Kilo Watts
IEA	International Energy Agency
LCD	Low-carbon Development
LCOE	Levelised Cost of Energy
LIC	Low-Income Countries
MWh	Mega Watt per Hour
O&M	Operations & Maintenance
OECD	Organisation for Economic Co-operation and Development
Pp	Percentage Points
PV	Photovoltaic
Quads	Quadrillion BTUs
RE	Renewable Energy
UN	United Nations
US	United States
USD	US Dollar

Acknowledgements

I would like to thank Andrew Scott (Research Fellow, ODI) for his continued guidance throughout the drafting of the paper, his numerous suggestions and insightful comments have helped shape the argument. I would also like to thank Tom Mitchell (Head of Programme, Climate Change Environment and Forests ODI) Nicola Cantore (Research Fellow, ODI) and Andrew Barnett (Director, Policy Practice) for their suggestions during the review process and in helping me further refine the analysis and presentation in this document and to Emma Lovell (Programme Officer, ODI) for her thorough review and editing.

Executive summary

Energy is an important ingredient in achieving economic growth, sustainable development, and human well-being. Importantly, the relationship between energy and economic development is bi-directional, such that energy availability enables economic development and this in turn results in an increase in energy consumption.

The cost of modern energy (both fossil fuels and clean technologies) will influence the ability of low-income countries (LICs, as defined by the World Bank[1]) to grow and compete internationally. These countries currently consume low levels of modern energy (both per capita and nationally) and consequently have under-developed energy services infrastructure. Their priority is to grow this base of energy services to cater to both their currently unaddressed and their potential future demands (for both economic development and poverty alleviation).

A lack of fossil fuel resources and the consequent increased dependency on fuel imports have left most of these economies disproportionately vulnerable to forces beyond their influence and control. In fact, a number of LICs (11 out of 25 countries for which data was available) already pay more than 10% of their Gross Domestic Product (GDP) (as an average of 2006-2010) to simply secure their oil supply (Economy Watch, 2011). This number is expected to rise in the future, given the transition from traditional energy sources (for example fuel, wood and waste) to modern energy systems. As the average price of fossil fuels in international markets is also continuing to rise, these countries will face even greater vulnerability to fuel markets and securing energy sources.

The need and urgency to 'de-carbonise' energy supply, stands at a centre stage of climate change debates. LICs among other low emission producing countries are in a spot where they need to rethink their energy and growth strategy by exploring alternative energy solutions. This potential deviation from the status-quo trajectory can emerge from either a reduction in the absolute level of energy consumed (through technology improvements for example) or a change in the nature of energy supplies. The former, as this paper will demonstrate, is unlikely, given the need to drive development. This paper therefore suggests that LICs need to rethink their energy and growth strategy by exploring alternative pragmatic, affordable, efficient and cleaner energy sources.

This working paper starts by attempting to clarify the motivation of LICs to support the adoption of low-carbon development (LCD) pathways. In an attempt to quantify this rationale we have taken electricity generation as a test-case. Our argument for LICs adopting LCD pathways is that these countries need to provide modern energy services to different strata of populations. Given that there are large populations living in rural areas, a dual challenge to driving access to modern energy services (such as electricity, transportation) exists: first, ensuring energy security for communities; and second, curbing the use of traditional (and often inefficient) energy systems in order to try and combat climate change. There is emerging evidence that in certain circumstances and locations decentralised renewable energy (RE) solutions can provide rural electrification through affordable, reliable, socially adequate and climate friendly energy systems (Glania and Rolland, n.d.; Bhattacharyya, 2006; Kaygusuz, 2011). In addition, RE technologies can offer greater opportunities for paid employment through alternative green jobs.

Our study of the financial case behind LICs adopting LCD trajectories, integrates (a) the levelised costs of different technologies, (b) the changing costs of RE technologies, (c) carbon markets, and the cost of carbon, and finally (d) rising costs of fossil fuels, into a single economic assessment. The key point of

1 Afghanistan, Kyrgyz Republic, Bangladesh, Liberia, Benin, Madagascar, Burkina Faso, Malawi, Burundi, Mali, Cambodia, Mauritania, Central African Republic, Mozambique, Chad, Myanmar, Comoros, Nepal, Congo, Dem. Rep., Niger, Eritrea, Rwanda, Ethiopia, Sierra Leone, Gambia, The, Somalia, Guinea, Tajikistan, Guinea-Bissau, Tanzania, Haiti, Togo, Kenya, Uganda, Korea, Dem. Rep., Zimbabwe.

this analysis is to understand at what point in time (if at all) the different renewable technologies achieve 'grid parity' with fossil fuel based technologies.

Through the examination of distinct economic scenarios, the analysis highlights that while additional financing (through carbon markets, subsidies and so on) is important in accelerating the adoption of LCD technologies, they are not a necessary condition. In the absence of vibrant financing markets, grid parity of renewable technologies is still an achievable objective over the next 5-10 years, except in the case of a small subset of technologies. The results are more encouraging when coal is held as the competing benchmark as opposed to natural gas - the latter witnessing a renaissance of sorts from the emergence of a number of unconventional sources. Nevertheless, the close nature of this debate is encouraging for the long term prospects of the adoption of renewable based technologies. The value of carbon markets in accelerating the adoption of these technologies does, however, suggest a need for some market based mechanisms to facilitate the migration of LICs away from fossil fuel based development paradigms.

Importantly, a lot of the analysis above is based on cost assumptions of constructing large generation plants. While these investments will have a place in the energy portfolio of LICs, another important component is likely to be off-grid, smaller installations. Interestingly, a number of studies have validated the results of this analysis for smaller capacity plants, thus highlighting that this is indeed a pragmatic developmental pathway.

1 Introduction

Over the industrial and now information technology ages of human development, economic growth has been highly correlated with the availability of low cost and high calorific value energy sources. Various forms of fossil fuels have been central to this argument, with oil and coal being the most prominent. This model however, is now being stretched with the realisation that future increases in coal and oil production will come at increasingly high financial and environmental costs. Even where the prospect of 'abundant' natural gas supplies exist (through unconventional sources), there are significant technological and environmental costs and concerns. The expected rise in direct and indirect financial costs is only half of the challenge. Rising energy costs have the potential to drive other commodity prices upwards. This will raise inflation, which in turn could lower macro-economic demand, create difficulties in sustaining economic growth, and ultimately result in increased unemployment.

The cost of modern energy (both fossil fuels and clean technologies) will influence the ability of low-income countries (LICs, as defined by the World Bank[2]) to grow and compete internationally. These countries currently consume low levels of modern energy (both per capita and nationally) and consequently have under-developed modern energy services infrastructure. Their priority is to grow this base of modern energy services (such as electricity, transportation) to cater to both their currently unaddressed and their potential future demands (for both economic development and poverty alleviation).

A lack of fossil fuel resources and the consequent increased dependency on fuel imports have left most of these economies disproportionately vulnerable to forces beyond their influence and control. In fact, a number of LICs (11 out of 25 countries for which data was available) already pay more than 10% of their Gross Domestic Product (GDP) (as an average of 2006-2010) to simply secure their oil supply (Economy Watch, 2011). This number is expected to rise in the future, given the transition from traditional sources (for example fuel wood and waste) to modern energy systems (such as fossil fuels). As the average price of fossil fuels in international markets is continuing to rise, these countries will face even greater vulnerability to fuel markets and securing energy sources.

From a developmental standpoint, while use of modern energy is vital to development, its impact on climate change (due to carbon emissions) is considered one of the greatest threats (IPCC, 2007), primarily because it is feared that it will affect the LICs first and worst. The consequent impacts will not only diminish gains from economic development, and pose incremental constrains on other actions, but LICs are also likely to be impacted by a higher number of climate-related disasters and food insecurity. LICs are likely to face a number of challenges in providing modern energy services to their countries: first, even though these countries have very low energy consumption and have contributed the least to climate change, they need to adopt sustainable practices to lower the impacts of these climatic changes in the future; second, the population of LICs is expected to grow from 919 million in 2005 to 1,473 million by 2030 (Jewell et al., 2010), which will multiply the stress on ecosystems and the competition for resources; third, LICs will inevitably look to expand their access to energy systems substantially for the millions that still live in energy poverty (with inadequate and unreliable access to energy provisions and services) through sustainable, reliable, efficient and 'climate friendly' or cleaner technologies.

This potential deviation from the status-quo trajectory can emerge from either a reduction in the absolute level of energy consumed (through technology improvements for example) or a change in the nature of energy supplies. The former, as this paper will demonstrate, is unlikely, given the need to

2 Afghanistan, Kyrgyz Republic, Bangladesh, Liberia, Benin, Madagascar, Burkina Faso, Malawi, Burundi, Mali, Cambodia, Mauritania, Central African Republic, Mozambique, Chad, Myanmar, Comoros, Nepal, Congo, Dem. Rep., Niger, Eritrea, Rwanda, Ethiopia, Sierra Leone, Gambia, The, Somalia, Guinea, Tajikistan, Guinea-Bissau, Tanzania, Haiti, Togo, Kenya, Uganda, Korea, Dem. Rep., Zimbabwe.

continue to drive development. This paper therefore suggests that LICs need to rethink their energy and growth strategy by exploring alternative pragmatic, affordable, efficient and cleaner energy sources. This is the focus of this paper.

Low-carbon development (LCD) debates thus far have, justifiably so, focussed on reduction strategies of current emission levels for higher, middle and emerging economies and have given little attention to the future energy consumption trajectories of LICs. This paper hopes to bridge this gap by attempting to explore the investment rationale for LICs to consider LCD pathways within their energy portfolio, with a focus on electrification. While other sectors such as transportation are equally important, we see electricity services as potentially impacting a large cross-section of the population in LICs. The paper starts (in Section 2) by laying out the linkages between development and energy by analysing trends across global (country) economic groups and patterns within LICs. Section 3 then moves to a qualitative assessment of what LCD could mean for LICs. Section 4 sets out an important analytical framework, that is then the basis of Section 5, where a range of financial scenarios are evaluated in order to highlight the financial case underlying any move towards an LCD trajectory by LICs. Finally, Section 6 summarises the analysis and attempts to open this debate up, by exploring related socio-economic issues.

Importantly, this paper makes a number of assumptions within the analysis comparing different modern energy types. A key example is the use of electricity as a representative of other energy issues for example transportation, facing these countries. The paper does not claim that there is a direct application of the results in one sphere to the other – in fact the technologies and approaches are vastly different. Nevertheless it does lay out a viable mechanism to evaluate a similar LCD trajectory in transportation and importantly, hypothesises that the results will be directionally similar. Finally, while this study has analysed a range of alternative assumptions and conclusions, it remains apparent that there is disparity in the data collection (given the various databases used) which could lead to different findings.

2 Role of modern energy services in economic development

2.1 Factors affecting energy consumption

It is well documented that modern energy services are important for achieving economic growth (through enabling enterprises, the transporting of goods and services, or simply by improving productivity), sustainable development, and human well-being (by helping to improve education and health facilities, and facilitating the production of food) (Funder et al, 2009; Kaygusuz, 2011; Kanagawa and Nakata, 2007). Through the vast literature that covers this nexus of modern energy services (such as electricity, transportation among others) and development, there is recognition that their relationship is inherently multi-dimensional and complex. This complexity emerges from differentiated interests and circumstances such as, rural and urban dynamics, supply and demand dynamics, household energy needs (and so on), and indeed how each of these aspects interact at different stages of a country's evolution (Byrne at al., 2011).

A number of analysts have attempted to explore and unravel the linkages between modern energy consumption and development, and have often done so on the basis of econometric models or through theoretical and empirical evidence - suggesting that energy use is a key enabler for development. There is also a strong population-energy link that threatens the sustainability of the existing energy sources (modern or traditional such as fuel wood). Specifically, that demand for energy (modern or traditional) increases as population grows, and concurrently impacts the total energy consumption. It is therefore theorised that a large share of the future growth (as a percentage increase) in the world's modern energy consumption will come from the developing countries (as validated by the compounded annual growth rates in energy consumption for different country groups in Figure 1) and that the middle and low income groups within these countries will drive up the future energy consumption. As the GDP of LICs increases, it will result in an increase in the incomes of the middle and lower income populations and therefore their ability to purchase modern appliances, which in turn will contribute to a growth in modern energy demand. Other than these factors, weather or geographic conditions can also affect the energy consumption (Darmstadter, 2004; Wolfram et al, 2012).

A look at historical per capita consumption patterns across different country income groups can help us quantify the expected change in energy consumption levels (Figure 1). Over the past four decades or so, LICs have actually seen broadly unchanged per capita modern energy consumption. Other than Organisation for Economic Co-operation and Development (OECD) countries, which themselves have seen relatively stable per capita modern energy consumption as well (driven primarily by gains in energy efficiency), every other non-OECD group has shown an increase (as measured by the compound annual growth rate (CAGR)). This increase is higher as income increases and therefore validates the modern energy-development nexus indicated previously[3]. Based on this historical data, it is very evident that should LICs get on a path of economic development, it would be reasonable to see between 1% and 2% increase in per capita energy per year. This, when combined with the fact that these countries will also see between 2% and 5% annual increases in population, suggests a very dramatic increase in modern energy needs.

The United States' Department of Energy's Energy Information Administration (EIA) estimates that global modern energy consumption will reach 721 quadrillion (quads) British Thermal Unit (BTU) (1 BTU = ~0.3 Mega Watts per hour (MWh)) in 2030, compared to 504 consumed globally in 2008, with 278 coming from the current 34 OECD nations and the remaining 443 quadrillion BTUs from currently 'developing' countries. Other forecasts (such as those from 3000quads, 2012) claim that these figures will go even higher to a developing world aggregate of 673 quads in 2030 (952 aggregated globally), an expected compounded growth rate of 5% (Fuller, 2011).

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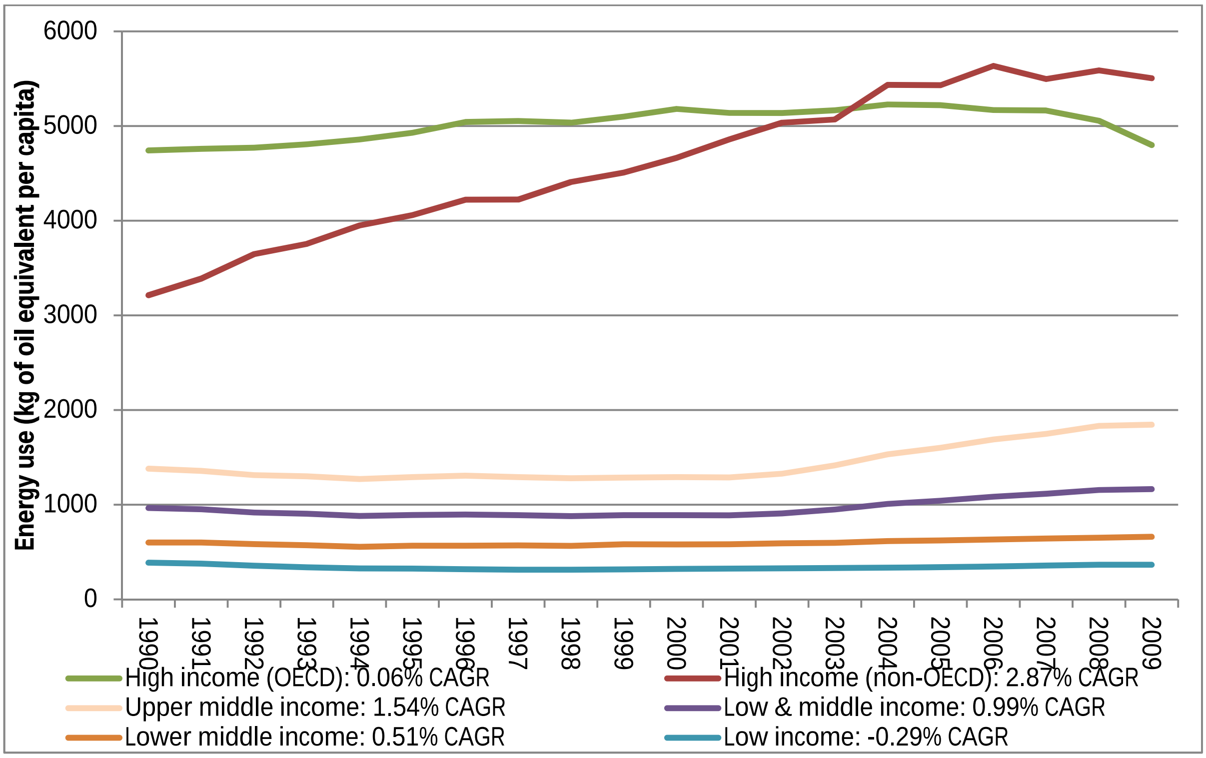
3 As counties develop there are more opportunities to reduce energy intensity, however total energy requirement almost always increases with development in the long term.

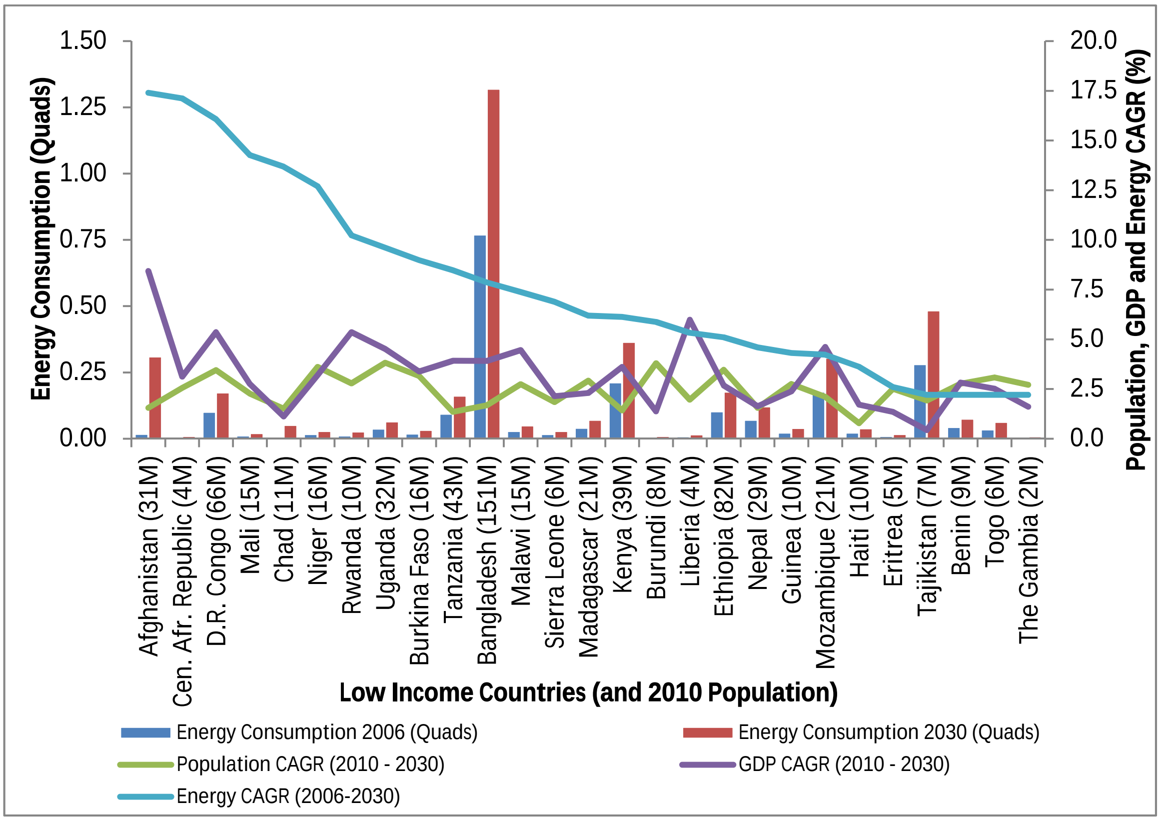
Figure 1: Per capita consumption of energy for different income levels (1971-2009)



Source: World Bank databank, own analysis

Within this larger aggregation of developing countries, forecasts for energy consumption at a country level can vary significantly depending on the source. Fuller (2011) has used a combination of current per capita energy consumption, projected population growth, and current and projected GDP to attempt this. In addition he has layered on the concept of a "paired" country to project out future per capita energy (and therefore aggregate energy) demand. In this approach, Fuller (2011) has attempted to identify countries that are on similar developmental trajectories except with a time lag between them. This then forms the basis of reasonably projecting how the time-lagged country's per capita energy consumption could be in its future, based on the current realities of the 'leading' country. This analysis, as captured in Figure 2, has helped illustrate how dramatically LICs modern energy consumption could grow (in percentage terms) over the next two decades. While, admittedly, there may be differences on projections for individual countries, as a group LICs are expected to increase their overall energy consumption at a rate that is far in excess of the 2% estimated for the developed world (as projected by the EIA).

Figure 2: Forecasted Energy, GDP and Population trends for selected Low-Income Countries



Source: Fuller, 2011, own analysis.

2.2 Global fossil fuel price trends

The dependency of economies across the world, on fossil fuels has emerged due to their high calorific value, ease of their availability, and relative lower cost, all of which have encouraged the development of goods and services that use these fuels as the primary energy source (Ebenhack and Martinez 2008). This perceived ease of access, however, is now changing quickly, morphing into undersupply, and consequently increased prices (most prominently for oil). There are several theories about when and how chronic oil scarcity will emerge, ranging from claims on physical reserves (Bentley 2002), to recovery rates, to oil pricing hypotheses (Leigh 2008; Helm 2011). Simultaneously there are different views on how this supply decline will ultimately be manifested. For instance Hubbert's theory concludes that the decline will be a mirror image of the petroleum growth trajectory (the second half of an inverted 'U'), whilst there are others who believe the decline will be a much more gradual slope (Ebenhack and Martínez, 2008). While the initial hypothesis is that the shortage of oil will almost certainly result in a spike in prices, in a scenario where demand moderates quickly or alternative energy solutions proliferate successfully, the price increase may not be as high (and could actually drop in some scenarios depending on shale gas resource realities) (Ebenhack and Martínez, 2008). The scarcity of oil supply and its consequent impact on the pricing of fossil fuels is important from the perspective of the future of developmental models. While a number of other factors influence the demand of fossil fuels such as technological innovation, taxes, and expectations, in the end it is the price (not cost) and the GDP that will affect the demand of the product the most (Bacon and Kojima, 2006 as cited in Hagman and Tekin, 2010).

As things stand, a number of key projections on oil have already been overshot, with prices in April-May 2012 in the range of US (United States) Dollar (USD) 110 per barrel (EIA, 2012b). To illustrate, EIA in its' Annual Energy Outlook, (2010) estimated that world oil prices would reach USD 95 per barrel in 2015, USD 108 per barrel by 2020 and USD 133 per barrel by 2035 (EIA, 2010). In fact the newer estimates suggest that the average real price of crude oil (reference case, in 2010 USD terms) would rise up to

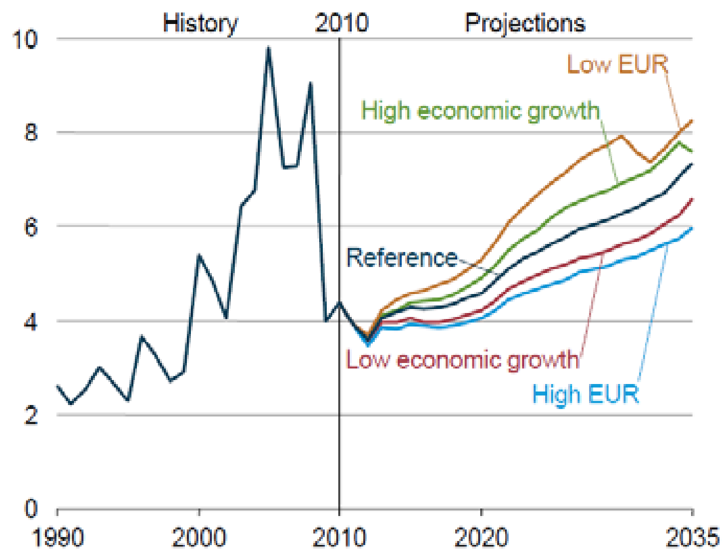
USD 125 per barrel in 2020 (IEA, 2012a) (see Table 1). Much like oil, projections on the price, production, and consumption of natural gas can vary hugely, based on the assumptions underlying the various projections. Recent technology advances in the access of unconventional gas sources (such as shale gas) have been reflected in a number of projections suggesting that the price of natural gas will decline and then rise (Figure 3). In recent years natural gas extraction has made advancements through drilling and hydraulic fracturing[4] technologies that have helped unlock many unconventional reserves that were previously uneconomical; the science, however, is still at its nascent stage and will likely take years to evolve (Broomfield, 2012). Importantly, a number of these developments have been limited to higher income and middle income countries. For instance, US and European companies spent about USD 160 billion on shale gas options during the first half of 2010 (Helm, 2011). Finally, projections on coal prices also differ, but one of the key assumptions resulting in this difference is the implementation of legal mandates to reduce greenhouse gas (GHG). Mine-mouth coal prices are projected to decline from USD 31.26 per ton in 2008 to USD 28.19 in 2025 (AEO 2010 reference case) and then stay relatively constant thereafter at USD 28.10 per ton till 2035 (EIA, 2010).

Table 1: Projections of World Oil Prices, 2015-2035 (2008 USD per barrel)

Projection and Source	2015	2020	2025	2030	2035
AEO2009 (reference case)	112.91	117.99	124.62	133.29	-
AEO2010 (reference case)	94.52	108.28	115.09	123.50	133.22
INFORUM	92.50	107.98	109.74	116.81	-
DB	93.18	105.48	114.65	121.16	125.42
IHSGI	85.07	81.93	74.86	77.27	80.03
IEA (Reference)	-	100.00	-	115.00	-
EVA	80.35	84.45	90.98	100.45	-
SEER (Business as usual)	79.20	74.31	69.73	65.43	-
SEER (Multi-dimensional)	99.03	101.52	105.81	113.91	-

Source: EIA, 2010

Figure 3: Annual average Henry Hub spot natural gas prices in five cases, 1990-2035 (2010 USD per mission BTU)



Source: EIA, 2012a (note EUR: Estimated Ultimate Recovery)

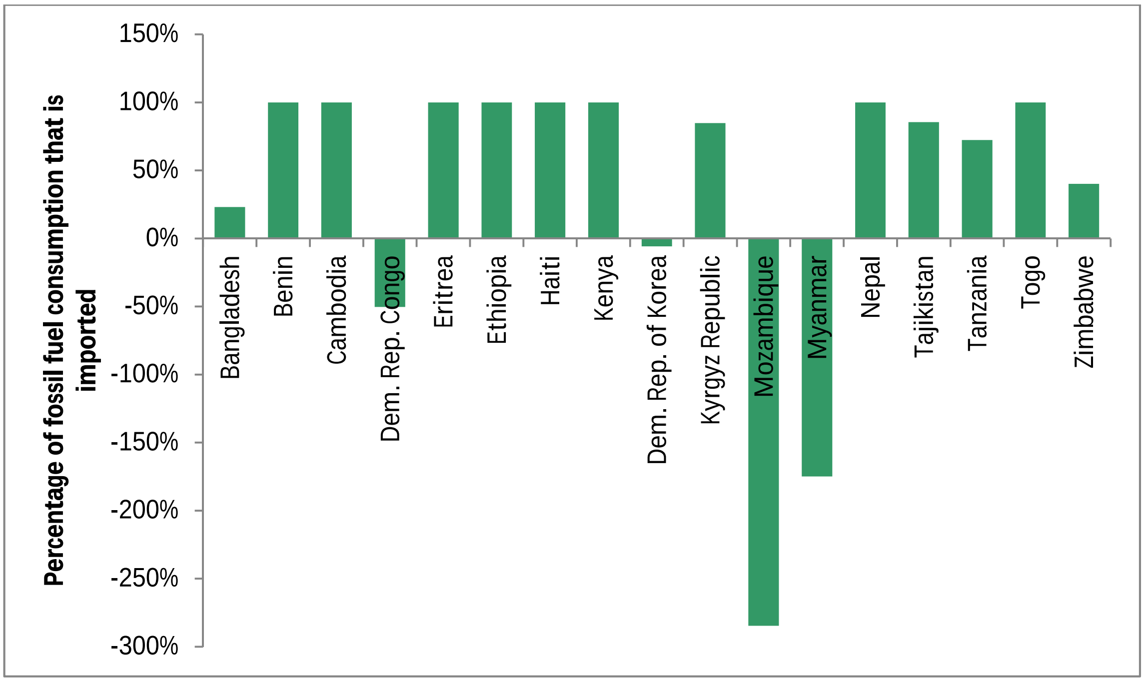
4 This involves pumping water, sand and chemicals underground to extract gas embedded in the rocks or other gas reserves.

The rapidly changing modern energy consumption patterns seen in lower middle and middle income[5] economies such as India and China, are exacerbating the supply-demand imbalance and therefore threatening to exceed even the highest price forecasts. These countries have economies that are structured towards oil and coal intensive manufacturing industries. Further, whilst transportation oil usage may currently be low in developing countries it can be expected to increase rapidly as economies grow (consider the correlation between per capita vehicle ownership and GDP). To establish scale, China's oil consumption in 2004 was 6.7 million barrels per day (at the time 13% of the world consumption), which was double that of 1995 (Leigh, 2008). It is projected that global oil consumption will rise from 86 million barrels of oil per day in 2007, to 111 million barrels by 2035 (U.S. International Energy Outlook, 2010 as cited in Watson, 2010). Similarly for coal, while it is believed to be one of the more abundant of fossil fuels (Heinberg, 2008 as cited in Lloyd and Subbarao, 2009), there are fears that it too may deplete faster than anticipated. China and India combined, are estimated to consume 72% of the projected increase of the world's coal from 120 billion Giga-joules (GJ) in 2004 to 210 billion GJ in 2030 (EIA, 2007 as cited in Lloyd and Subbarao, 2009).

2.3 Energy Security: Growing Reliance on Oil and Gas Imports and Fuel Price Volatility for LICs

As we think about the energy future of LICs, it is also worth considering how this demand will be served. A majority of the world's fossil fuel reserves are concentrated in a small number of countries. The middle eastern belt lays claim to 45% of the world's coal, 70% of the crude oil and 68% of the natural gas reserves with very few LICs elsewhere in the world having any fossil fuel reserves at all (Resources for the future, 2003). Therefore, by sheer geographic location, many LICs are at a disadvantage to begin with (Figure 4).

Figure 4: Percentage of fossil fuel consumption that is imported (selected LICs, 2009)

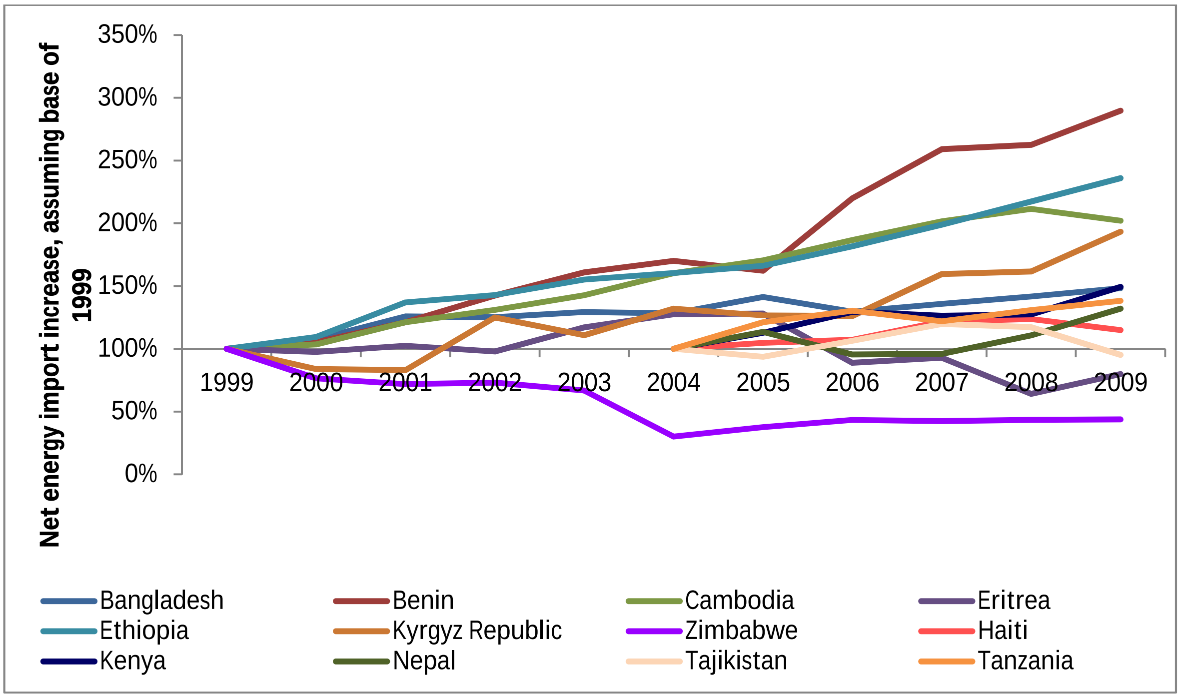


Source: World Bank Databank, own analysis

5 World Bank classification

Even where LICs have large fossil fuel reserves, there is no guarantee of growth. This, in literature has been put down as the 'resource curse', a scenario where factors such as weak political systems, conflict within the societies and poverty are actually reinforced by the abundance of a scare resource (Stevens, 2003). Oil producing LICs often suffer from an extreme case of enclave type economies in which the investment/profit motive is externally dominated and the challenges of diversification are not met (Ebenhack and Martinez, 2008). For instance, least developed countries[6] such as Angola, Nigeria and Equatorial Guinea, that have fossil fuel reserves, either don't have the resources to convert crude oil into petroleum, or don't have the markets and infrastructure that would attract investments from international corporations. In Myanmar for example, captive gas resources have raised the interests of many Asian countries, but not of the western world, given its unpredictable political and economic environment (Lahn, 2007). Afghanistan is another example of an unstable economy, in which Western countries have avoided making investments in, despite the large oil and mineral deposits found in the country (Simpson, 2011).

Figure 5: Change in fossil fuel imports for selected LICs (1999- 2009) (total fossil fuel consumed * % fossil fuel imported = total fossil fuel imported)



Source: World Bank Databank, own analysis

The majority of inhabitants in LICs consequently do not have access to modern energy services. Globally there are 3 billion people (a large section of whom reside in LICs), who depend on primitive and harmful fuels (such as coal, kerosene, fuel wood) (Kaygusuz, 2011) and about 1.5 billion have no access to electricity (UN, 2010, p.7), indicating a significant constraint to enhancing their livelihood, socio-economic growth and general wellbeing. As a result of moving away from these inefficient energy sources (such as fuel-wood and use of kerosene for lanterns), towards more modern sources, a number of countries (including most LICs), increasingly rely on imports to meet their energy needs (Figure 5). These imports require enormous amounts of foreign exchange every year, making these countries vulnerable to international fuel price volatility. For example, Rwanda imports all the oil it consumes, which in 2008 was USD 210 million or 4.7% of its GDP. The International Energy Agency (IEA) estimates that an increase of just USD 10 in oil prices can reduce the GDP growth in Asia by 0.8% in Asian countries and by up to 1.6 pp (percentage points) in countries that are highly dependent on imports

6 World Bank classification

(FAO, 2008, p.18). Rwanda's dependence on oil imports is expected to grow (forecasters suggest oil imports could be 30% of its GDP in 2030) and has put the country's development at risk from fluctuating fuel prices. Any repeat of the 2008 oil price inflation (an almost 20% increase at its peak) could be devastating for the local economy (King, 2011, p. 9). In 2010, 9 (out of 25 countries for which data was available) LICs paid in excess of 15% of their GDP to simply secure their oil supply (Economy Watch, 2011) (it would be reasonable to assume that countries where data is poor have even similar or worse energy profiles). These economies are likely to be negatively affected by continual increases in the real oil prices and price volatility (Bacon and Kojima, 2008; Bacon, 2005). In light of the argument above, it could therefore be valuable for LICs to re-orient their growth processes and invest suitable thought and effort into charting out their future energy portfolios.

3 What does low carbon translate into for LICs?

It is clear that rising global fuel prices and resource scarcity are making LICs increasingly vulnerable to securing energy services. While there is a mid-term argument that suggests that oil can be replaced with other low cost, relatively abundant and lower emission fossil fuels (such as. shale gas, tar sands, natural gas), it is important to note that these too have a finite life span and come with their own challenges. For instance the hydraulic fracturing technique (for natural gas extraction) can have serious environmental (such as contamination of ground water) and social (such as change of land use) implications if improperly executed (Broomfield, 2012). It is therefore imperative that countries begin evaluating policies that will reduce the impact of current shocks (such as fuel price volatility) and strengthen their ability to cope with future shocks (such as climatic changes) beyond just the medium term.

With this goal in mind, actions to modify energy sector behaviours can be grouped into three broad categories: (i) reducing energy use by changing behaviour patterns towards less energy intensive activities, (ii) reducing energy use by adopting a developmental trajectory that requires less energy based on the use of more efficient means of production, and, (iii) adopting fuel switch technologies (LCD pathways). Most LICs do not have much scope to reduce their energy use given already existing low usage. The pursuit of energy efficiency is an enduring target for all economies. Therefore, from an economy-wide investment and capability standpoint, there is a need to diversify the energy source portfolio.

In this context, LCD, 'green growth' or the use of modern renewable energy (RE) (such as solar photovoltaic (PV), wind, modern biomass etc.) technologies have gained much focus within the policy debate for developing countries (Mulugetta and Urban, 2010, Urban, 2010). Although the origins of LCD within the international developmental debate landscape have been fairly recent (since 2007), its linkages to climate change mitigation, sustainable development, and now the context of green growth have been discussed in a large body of literature (Tilburg et al., 2011 amongst others). It has been suggested that LCD can be achieved through equitable contributions of (i) deep cuts in the GHG emissions, (ii) increased usage of energy efficient and modern RE technologies and (iii) evolution of behavioural and consumption patterns; that combined, would reduce carbon emissions while ensuring developmental needs of all within a society.

From an overall development perspective, LCD, through the use of modern RE technologies can offer social, economic and environmental (the three pillars of sustainable development) benefits to the poor, unlike conventional technologies such as coal and oil. LICs have large rural populations that are dependent on fuel wood as a primary source of energy. As these countries grow in the future, they will require long term sustainable energy sources. Low-carbon solutions (particularly off-grid/mini or micro grid RE) can be beneficial in decentralising power generation as a tool for future energy production in rural settings, particularly for low demand and smaller scale energy solutions (Reiche et al., 2000).

From an economic perspective, modern RE technologies can offer opportunities through alternative green jobs. The RE industry, depending on the nature of production stages, has the potential to create more employment opportunities for both skilled and unskilled workers amongst local communities and grow the overall economy of a country. The oil industry, on the other hand, creates fewer jobs in comparison to its contribution to gross national product (GNP) and government revenues (Sachs, 2006). For instance, Angola has seen less than 10,000 local people employed in oil and gas companies, where the industry accounts for 40% of the total GDP and 90% of exports. In spite of the profitable nature of this commodity production industry, two thirds of the population still live below the poverty line (on less than USD 1 dollar a day) (Ebenhack and Martinez, 2008).

These modern RE technologies can offer additional financial benefits for the poor. Whilst there are no specific studies supporting this theory, there are a number of examples seen within the literature. For instance, in Tunisia wind and solar PV powered pumping is being used to help small vegetable farmers as a reliable alternative to the currently used diesel power (GNESD, 2007). Modern RE power generation can therefore be used as a mechanism for insulating communities from market price fluctuations in the global or national energy sector in these low-income countries. To further support rural electrification, certain countries such as Argentina, China, South Africa and Sri Lanka are now designating certain geographic areas as targets for off–grid electrifications (Beck and Martinot, 2004).
Further, modern RE technologies help advance environmental stewardship and reduce the dependency of the rural poor on fossil fuels. Modern RE technologies are carbon neutral and therefore, as discussed above, will help reduce the effects of climate change. These low-carbon technologies, in addition, can have a number of ancillary social benefits by improving health (lower instance of respiratory problems due to reduced use of kerosene and fuel wood), or increasing social capital for women (Thakuri, 2009). Analogues exist for other modern RE technologies such as improved flood control and better water channels to improve farming opportunities, and local water storage facilities that result in reduced travel time (enabling women in the community to focus on 'value added' activities including supporting the learning and development of their children) through micro-hydro technology applications. Community groups which have been established to manage such facilities have also experienced 'softer' benefits such as empowerment and participation for community women (Egre and Milewski, 2002; Katuwal and Bohara, 2009; Nguyen, 2007).

From an operational standpoint, countries have initiated their journey onto LCD pathways through a range of approaches. A majority of the LCD plans focus on pre-existing domestic needs, priorities and resources. "China's Low Carbon Development Path to 2050" report summarises the Energy Research Institute of China's National Development and Reform Commission's view that that the essence of LCD is to enhance socio-economic systems through reduced carbon emissions (Yuan et al., 2011). In its pilot of setting up low-carbon provinces and cities across the country, this government body targeted manufacturing and consumption practices with a view to reducing resource intensity and creating more ecologically sustainable energy systems (Luo, 2008 and Xia 2008 as cited in Yuan et al., 2011). Rwanda, on the other hand has committed to increasing its electricity access from 6% to 35% by 2020 (which is quite low in comparison to other countries but is a start to future energy intentions). Its LCD plans encourage interventions in sectors such as energy (for instance to promote RE, efficient stoves, hydro projects and so on) in addition to promoting sustainable practices in other sectors such as agriculture, waste disposal and forestry (Jean-Claude, 2008).

4 Cost analysis of energy options

Having covered (i) the developmental need of LICs for modern energy services in the future, (ii) the financial challenges of fossil fuel prices (that represent the changing world demand-supply dynamic), and (iii) the sustainable development benefits (economic, social and environmental) of exploring LCD pathways, there is a fourth piece of the 'jigsaw' – the financial case of the LCD pathway itself, in comparison with any 'business-as-usual' trajectory.

In an attempt to quantify this, we have taken electricity generation as a case study. Clearly any functioning economy uses modern energy services in a number of forms to achieve a variety of outcomes, for example, transportation, production of goods and services, agriculture and cooking. As such, the LCD pathways for each of these would be very different; again as examples, it could be natural gas for transportation where previously diesel or petrol were used, or, renewable-based generation for electricity, replacing coal. From this portfolio of modern energy forms, however, for most economies, electricity tends to be one of the largest services used, and therefore has been selected as the basis of our analysis below.

An examination of the financial case behind LICs taking LCD trajectories in electricity generation will require a holistic comparison between the various options. A comparison of capital costs or of annual operational costs will each present single 'point-in-time' values and result in skewed analysis. This is because the former does not take into account the full lifetime of the operations and maintenance (O&M) costs involved, and the latter does not appropriately value output fluctuations over time. In fact, by itself, a comparison of upfront capital investment is often heavily weighted in favour of fossil fuel plants given the significant maturity in expertise and manufacturing as opposed to RE (almost any technology) plants of similar generating capacity. When comparing O&M costs (incurred over the 20-30 year life of the plant) a number of studies have suggested that renewables based power plants have lower O&M costs given the absence of costly fuel, thermo-kinetic systems and the increased application of electronic control (as opposed to a combination of electronic and physical control for fossil fuel plants). Finally with regard to the cost of fuel: while there is a significant cost to fossil fuel, one that has shown an upward trajectory with a high degree of volatility, for RE solutions, fuel can be broadly considered low (or no) cost.

Therefore, to better understand the nature of the financial arguments for and against a particular electricity source, one of the key concepts that has been used and improved on over a number of years has been of "levelised cost". The value of assessing levelised costs is that it is able to encompass each of these three major cost categories in the life of a generation plant and combine them with the "capacity factor" of the plant. The argument against modern RE (particularly solar, wind and hydro) has often been the variability in supply (given the variability in sunlight, wind speeds and so on.) and therefore the lower energy generation capacity utilisation (see 'Capacity Factor' in Table 2). This low capacity factor has made the premium price paid for fossil fuels seem worth it from a financial standpoint. The 'levelised cost of energy' (LCOE) is therefore extremely valuable in avoiding short-term myopic conversations by capturing all these costs and operating realities in a single and financially sound number (Lacey, 2011; Borenstein, S., 2011; ESMAP, 2007).

Table 2: Estimate Levelised Cost[7] of New Generation Resources ($/MWh)

Plant Type	Capacity factor (%)	U.S. Average Levelised Costs for Plants Entering Service in 2016 (not including any incentives)				
		Levelised Capital Cost (USD)	Fixed O&M (USD)	Variable O&M (including fuel) (USD)	Transmission investment (USD)	Total system levelised cost (USD)
Conventional coal	85	65.5	3.9	24.5	1.2	95.1
Advanced coal	85	74.7	7.9	25.9	1.2	109.7
Advanced coal with CCS	85	92.9	9.2	33.3	1.2	136.5
Natural Gas-fired						
Conventional Combined cycle	87	17.5	1.9	44.6	1.2	65.1
Advanced Combined Cycle	87	17.9	1.9	41.2	1.2	62.2
Advanced CC with CCS	87	34.7	3.9	48.6	1.2	88.4
Conventional combustion Turbine	30	45.8	3.7	69.9	3.5	123.0
Advanced Combustion Turbine	30	31.7	5.5	61.3	3.5	102.1
Advanced nuclear	90	90.2	11.1	11.7	1.0	114.0
Wind	34	83.3	9.5	0.0	3.4	96.1
Wind –offshore	34	209.7	28.1	0.0	5.9	243.7
Solar PV	25	194.9	12.1	0.0	4.0	211.0
Solar Thermal	18	259.8	46.6	0.0	5.8	312.2
Geothermal	91	77.4	11.9	9.5	1.0	99.8
Biomass	83	55.4	13.7	42.3	1.3	112.6
Hydro	53	78.5	4.0	6.2	1.8	90.5

Source: EIA, 2010

The table above lays down key components of the LCOE per major technology type in the US. For each technology type, fossil fuel (coal and natural gas based), low carbon (nuclear) and RE (wind, solar, geothermal, biomass and hydro) based technologies, there is an attempt to set out benchmark costs. While clearly each of the costs will vary based on individual implementation approach and project structure, this table does provide a starting point for each. Capacity factors for each technology set out the relative performance of the infrastructure for each plant type, such as low solar plant capacity factors are due to (a) the relatively poor conversion of solar light to electricity and (b) the fact that these plants cannot operate 24 hours a day, 365 days a year because of fluctuating climatic patterns. For wind, this factor is higher because of better ability to convert energy. Given the maturity in technologies and the more 'predictable' fuel supply fossil fuel based plants have significantly higher capacity factors. Often the only reason these are not 100% is the need for downtime to allow for inspection, maintenance and repair. Levelised capital costs in this table, a reflection of the up-front plant setup costs (per unit output of electricity), also reflect the relative maturity of different technologies and the physical challenge in setting up plants. Consider off-shore wind, where physical challenges, and solar, where the need for infrastructure spread out over a large physical space, add significant costs to plant set up. Moving to O&M costs, the absence of mechanical parts helps keep variable O&M costs for a number of the RE plants down to a minimum. Nevertheless, there is still a particular amount of regular maintenance that needs to be undertaken regardless of the size of the plant, and is captured under 'fixed O&M' costs. Given the high-tech nature of the equipment used, this cost tends to be higher for

7 The costs shown in Table 2 are national averages. Key factors contributing to levelised costs include capital cost of construction of plant, time required for construction, non-fuel costs of operating the plant (operating and maintenance O&M costs), fuel costs, cost of financing, and utilisation of the plant. The values in the table do not show any incentives such as tax credits (EIA, 2010).

renewables based power plants. Finally, for transmission costs, renewables based plants often tend to be far away from electricity consumption centres (consider how solar plants are located in desert plains) and therefore this cost group tends to be higher for plants of this nature compared to fossil fuel plants.

Equation 1: Levelised Cost of Energy

Formally, levelised cost of energy (LCOE) is viewed as the present value per-unit cost of electricity generated by the plant. Decomposed, it is a ratio of the present value of the life-time costs of the plant divided by the present value of the electricity generated during its useful life. Another way of looking at LCOE is the present value of the price at which each unit of electricity will need to be sold for the project to break-even

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where
LEC = Average lifetime levelised electricity generation cost
It = Investment expenditures in the year t
Mt = Operations and maintenance expenditures in the year t
Ft = Fuel expenditures in the year t
Et = Electricity generation in the year t
R = Discount rate
N= life of the system

Source: Short et al., 1995

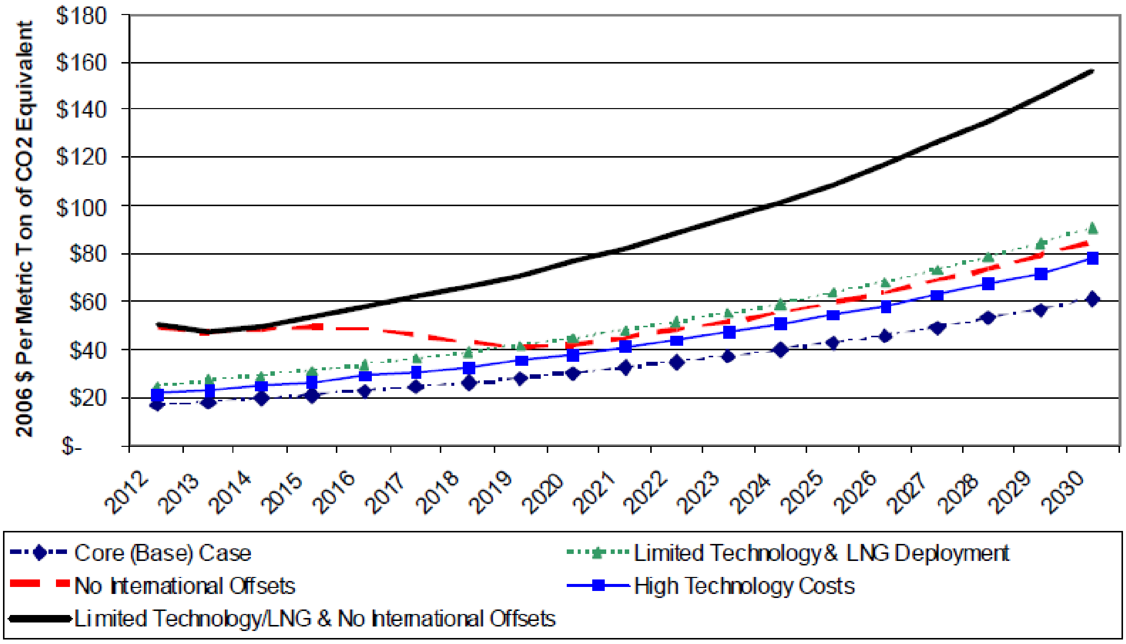
To build on LCOE as a uniform framework for cost assessment in the context of an LCD trajectory for LICs, it is important to consider a few additional factors. First, it is worth to noting how capital costs are constantly falling for RE technologies such as photovoltaic (PV) cells. Consider how installed global solar PV capacity has increased 40% annually from 2000 (0.26 Giga watts (GW) to 16.1 GW in 2010) – driven by rapid strides in technology. These dramatic improvements coupled with benefits from scales in manufacturing have helped reduce manufacturing costs to a fraction over the same period. Studies suggest that prices of PV panels have been dropping faster than any other electricity generator - raising the possibility that, as installations in Hawaii and California have shown recently, solar PV could achieve grid parity (Branker et al., 2011).

Second is the cost of the associated infrastructure, specifically transmission and distribution networks. Admittedly, the averages above hide that level of detail. There are clearly cases, particularly given the geographically dispersed rural nature of LIC communities, where both transmission and distribution costs will be disproportionately higher than the numbers above suggest. While this paper will not attempt to quantify the range of possible outcomes and their implications with regards to these cost brackets, it is worth considering that these costs will likely be higher for solar and wind based technologies since these are located in remote areas more often than plants based on other technologies. Nevertheless where these technologies are being used as off-grid solutions (often the case in LICs) these infrastructure costs may not be applicable.

Third is the cost of carbon. An outcome of the Kyoto protocol was the development of tradable certified emission reduction units (CERs) which has since led to the creation of carbon markets. While carbon prices, as with any commodity in recent times, have ebbed and flowed, the key factor is that they can play a valuable part on both sides of the comparison. A requirement to purchase credits has the potential to add significantly to the total costs required to operate fossil fuel generation facilities. Analogously, the sale of CERs from low-carbon RE generation facilities has the potential to offset an equally significant cost basis for these facilities. Consider, for example, that a number of projections

indicate that carbon prices will rise over the next two decades (on a real basis) by somewhere between 200% and 300% (see
Figure 6).

Figure 6: EIA's Projections of CO2 Allowance Prices (2006 USD per Metric Ton of CO2 Equivalent)[8]



Source: Supporting spread sheets for EIA, Energy market and economic impacts of S. 2191, the Lieberman-Warner climate security Act of 2007 as cited in Kaplan, 2008.

Fourth, is the consideration of fiscal policy approaches, as represented by taxes and subsidies, and their impact on discount factors (in combination with expectations on inflation). On one side, there is the possibility of punitive taxation on conventional energy use most often from the perspective of 'usage of environmental public goods'. On the other hand, there is the possibility of subsidies attached to RE technologies to drive their usage. Given current regulatory regimes (at national and multi-national levels), and the pressure for fiscal consolidation across developing and developed countries, it is foreseeable that any subsidy will be gradually reduced. Simultaneously putative taxes will likely continue or indeed increase. Germany for instance, has proposed to discontinue subsidies on coal mining in a socially adequate manner by the end of 2018 (G20, 2010). While there is a big question of the role of political economy in the reduction of subsidies in LICs, if such an approach is implemented it can skew these countries towards adopting low-carbon technologies more quickly.

8 Using the range of forecasts from Figure 5, USD 35 is the expected cost of a CER during 2015 - 2020

5 Economic case for LCD pathways

We have attempted to integrate each of these components (a) levelised costs of different technologies, (b) changing costs of RE technologies, (c) carbon markets, and the cost of carbon, and finally (d) projections for costs of fossil fuels, into a single economic assessment. Given the country specific nature of fiscal policy, we have not included any assumptions on this in our analysis. Not assuming any incremental tax subsidies (for RE) or penalties (for fossil fuels), in our view makes the outcomes more robust by. Before we review the results however, it is important to lay out the key assumptions and the underlying rationale.

Importantly, the LCOE bases that we begin with are estimates from the EIA for electricity generation plants in the US. As we think about how these costs translate to LICs, it is worth considering each of the main cost brackets individually. First, material capital and O&M costs will be higher in LICs, driven by a general lack of infrastructure and the need to import most components; nevertheless, this increased cost will be true for each of the different technologies. Our view is therefore that while the absolute USD value of results may be different, relative cost assessments (and rankings) will not. Second, for labour costs, given significantly lower average wage rates (particularly for non-specialised work) in LICs, it is expected that this would help reduce costs for the life of the plant. This again should be true across the different types of plants (fossil fuel and renewable) and will therefore not alter the relative cost ranking. Third, with regards to fuel costs, since these are priced in international markets, there will be minimal changes for LICs. Fourth, capacity factors are related to the actual location of a plant rather than the US versus an LIC; yet additional data sources have suggested that capacity factors are similar across the world (Kuang, 2012; West, 2011). Studies in Southeast Asia suggest that the range for this factor for solar plants in Thailand and Malaysia is from 18% to 25%; our report has assumed 25%. Similarly, wind capacity factor in these countries is from 20% to 32% (Kuang, 2012), against our estimate of 34%. This, it is assumed, is because RE projects, globally, (a) are installed only in those locations with at least a certain minimum level of the fuel (e.g. wind or sunlight) and (b) use technology with the same efficiency levels. Therefore as opposed to attempting to quantify the impact of selective locations, we have left this assumption untouched. Our assumptions for these three cost brackets are validated at a summary level in a study undertaken by West (2011) that suggests that for capital, O&M, and fuel costs, LCOEs fall within similar ranges as OECD and non-OECD countries for most technologies at an (aggregate) level. Lastly, with regards to discount factors, while the EIA, for its base case, has assumed 6.8%, for the calculation of LCOEs, borrowing costs in LICs are higher compared to the US. Unfortunately, given that we are beginning with benchmark estimates of LCOE, we are unable to analyse the impact of particular changes in discount rates. This is a limitation of the paper. Nevertheless an analysis of different projects across South East Asia suggests that as discount rates increase, the cost of projects also increases (Kuang, 2012). This consequently means that LICs will face higher absolute costs in construction, O&M and so on for different plants; importantly the cost differential will not be uniform across different technologies.

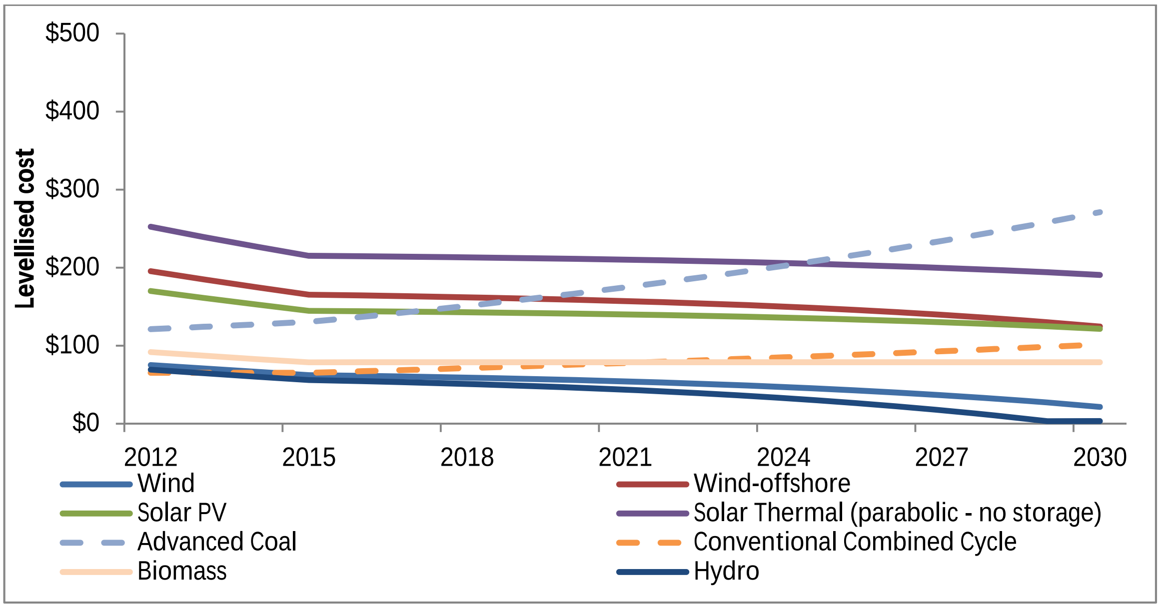
Moving away from LCOE, there are three additional assumptions worth clarifying (see Table 3). First, for carbon (or CER) prices, we have assumed a constant price of USD 7.5 based on the fact that carbon prices over 2011 and 2012 (Forexpros, 2012) have averaged between USD 7 and 8. Second, for carbon offsetting, we have assumed two possible outcomes as a starting point (the 'base scenario') (i) that renewables based generation plants will be able to sell 10% of their avoided carbon footprint, and (ii) that the renewables-based generation will not be able to sell any carbon offset. The belief is that these are conservative assumptions but reflect the concern of regulatory mechanisms in place. Third, and finally, for cost inflation, we have assumed that fossil fuel based plants will see a cost escalation of 3-5% per annum across different fuel types (broadly consistent with EIA forecasts). This is expected to include any fuel cost changes as well as general inflation based cost increases. The range is designed to be conservative (low) since it can have a significant impact on the outcome, and the desire is not to let results be dictated by this assumption. For renewables, we have assumed a small (2%) annual cost escalation after a period of price reduction (5% per annum) as dictated by the current trajectory. This assumption has been based on the view that the sustained drop in costs for renewable technologies seen thus far will not continue for another two decades and that production capacity and technology constraints will reverse the trend of falling costs.

Table 3: Sensitivity scenario's for LCOE analysis

		Base scenario	Optimistic scenario	Pessimistic scenario
Cost inflation of fossil fuels (annual)	2012-2015	Natural Gas: 0% Coal: 3%	Natural Gas: 0% Coal: 3%	Natural Gas: 0% Coal: 2%
	2016-2030	Natural Gas: 3% Coal: 5%	Natural Gas: 3% Coal: 5%	Natural Gas: 2% Coal: 2%
		Fossil fuel price inflation reflects IEA expectations, except for natural gas where prevalence of unconventional sources is expected to result in stable costs	Slightly higher expected cost inflation of oil in the longer term	Minimal cost increase in fossil fuel costs
Cost inflation of renewables plant materials (annual)	2012-2015	-5%	-5%	1%
	2016-2030	2%	0%	1%
		US Department of Energy estimates costs have fallen 6% per annum since 1990, however this cannot continue ad-infinitum (Naam, 2011).	Little cost escalation of renewables in the longer term	No further possible gains in cost reduction for renewables
Carbon CERs for sale (as a % of carbon offset)		(i) 10% (ii) 0%	20%	0%
Carbon prices (USD per COteq)		USD 7.50 2012-2030	13% increase per annum from USD 7.5 in 2012	---
		Carbon prices have been between $7 and $8 since 2010	Expectation that carbon prices will be USD 70 in 2030, requiring a 13% change per annum	No carbon market exists

Analysing this base scenario (see Figure 7 and Figure 8) illustrates the current challenge faced by LICs. The key point of focus is to understand when the different renewable technologies achieve ‘grid parity’. This is when, from a financial standpoint, the cost of electricity at the grid is the same irrespective of the source (the lines in the chart intersect with lines representing fossil fuel costs). In this scenario, some renewable (solar thermal and off-shore wind) technologies do not reach grid parity even up to 2030. Only on-shore wind, and ‘mature’ renewables based hydro and modern biomass technologies seem to come close to competing with fossil fuels. Given the varying topographical and geographical constraints of different countries this effectively rules out renewable based technologies for certain LICs. In addition, given the on-going and persistent global economic growth crisis and increasing tendency of oil majors to tap hereto unexplored regions, there is a possibility that fossil fuel prices will not increase over the next few years (particularly in the case of gas). This would push out the time horizon when renewable-based generation can achieve ‘grid parity’ and can become competitively priced. With the useful life of most generation plants between 20 and 30 years, this effectively delays the investment decision by another generation.

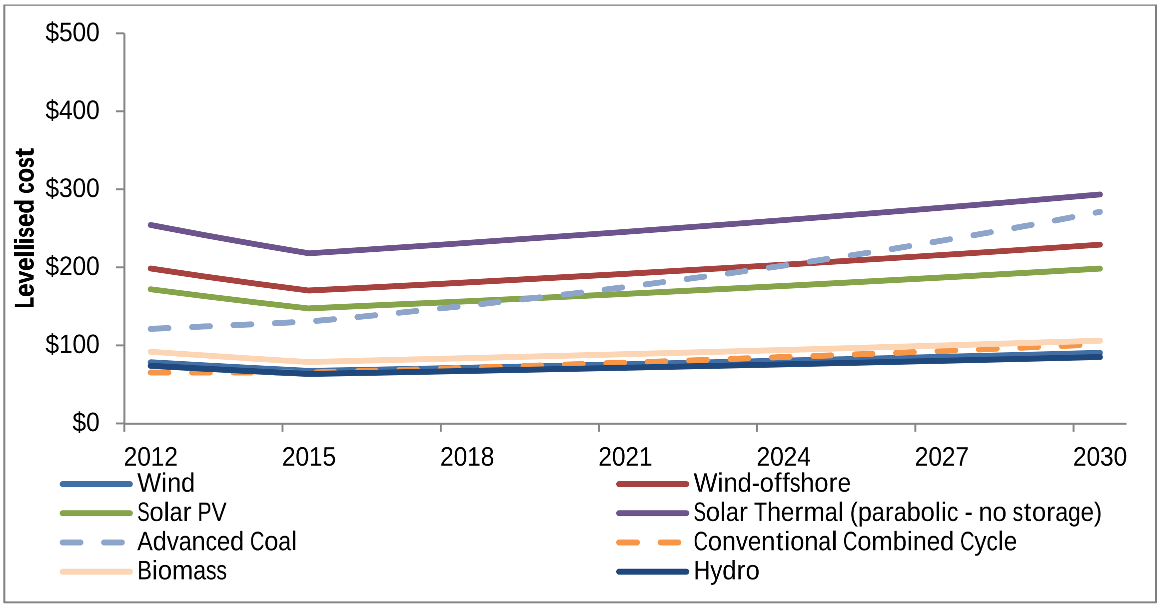
Figure 7: Base scenario (with carbon offset)



Source: Carbon price from Figure 6, carbon footprint from 'Danish energy authority', levelised cost from Table 2

Key assumptions: LCOE for conventional fuel powered plants rises at 0% (natural gas) and 3% (coal) from 2012-2015 and then at 3% (natural gas) and 5% (coal) from 2016-2030 (this would also include fuel cost inflation); LCOE for renewable powered plants continues to fall at 5% annual (till 2015) and then rises at 2% annually till 2030; renewable plants are able to sell 10% of the carbon offset

Figure 8: Base scenario (without carbon offset)



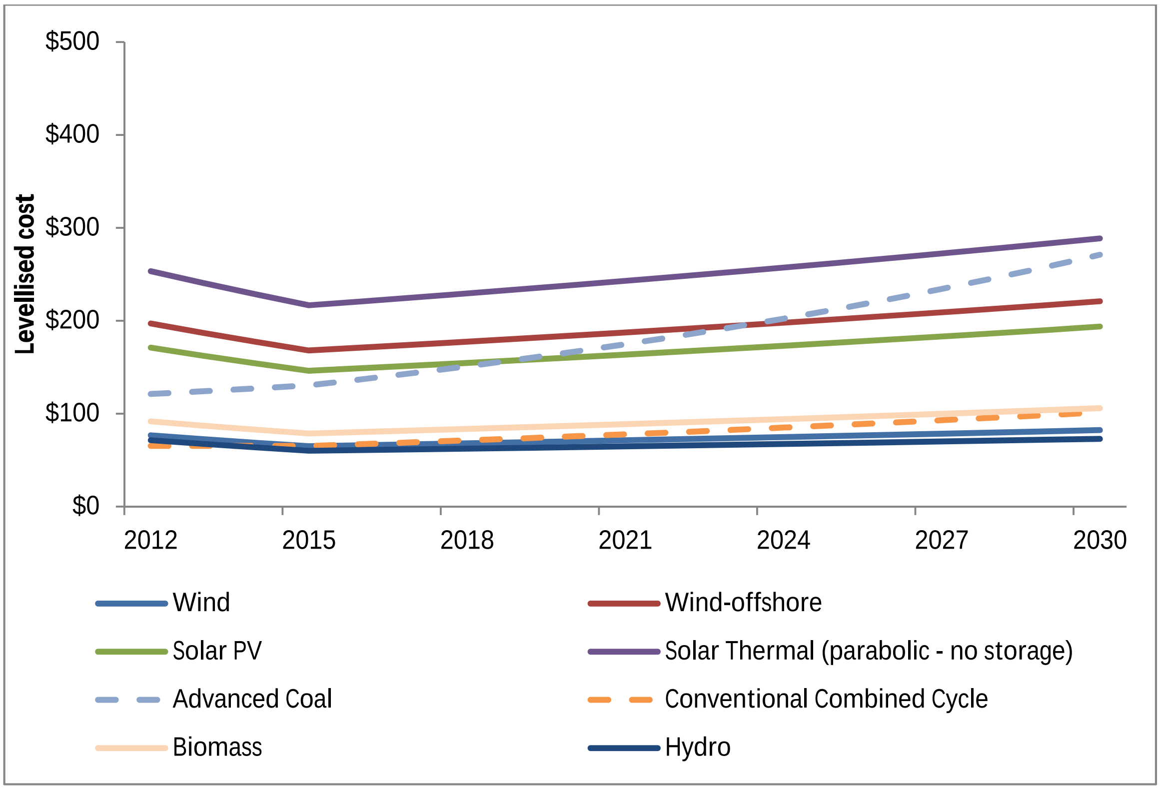
Source: Carbon price from Figure 6, carbon footprint from 'Danish energy authority', levelised cost from Table 2

Key assumptions: LCOE for conventional fuel powered plants rises at 0% (natural gas) and 3% (coal) from 2012-2015 and then at 3%(natural gas) and 5% (coal) from 2016-2030 (this would also include fuel cost inflation); LCOE for renewable powered plants continues to fall at 5% annual (till 2015) and then rises at 2% annually till 2030; renewable plants do not sell any carbon offset

To further explore how different macro-economic and carbon market dynamics can shape this decision for LICs, we have defined two additional scenarios (see Figure 9 and

Figure 10). The underlying premise of the 'optimistic' scenario is a robust carbon market and increasing costs of fossil fuels. In this scenario (see Table 3), we have assumed that carbon prices rise at approximately 13% per annum (to USD 70 in 2030). This is partially consistent with the base case EIA projections till 2030 with an added degree of conservatism. The EIA projections have proved to be higher than actual market prices (for instance those from the European Union Emissions Trading Scheme (EU ETS)) and therefore we have taken EIA's projections of carbon prices in 2006 USD (
Figure 6) terms as the nominal projections for each year (that is, we have not added on an additional component of inflation for future years). This effectively discounts carbon prices by 3-5% a year and, we believe, sufficiently suppresses the projections given current price realities. This assumption is validated by the estimates of a number of institutions (including private banks) which have suggested that a target nominal carbon price of USD 70 in 2030 is achievable (Dellero, 2008). To complete the definition of this scenario, we have assumed fossil fuel prices rising by between 3- 5% per annum over the long term (based on the fuel type) and renewable technology prices remaining steady (after continuing the trajectory of falling prices for the next 3 years). Finally we have assumed a 20% sale of carbon offset from RE. Our 'pessimistic' scenario is one where carbon markets cease to exist. In addition, fossil fuel and renewable technology based cost inflation is expected to be similar in the longer term (between 1 and 2% per annum).

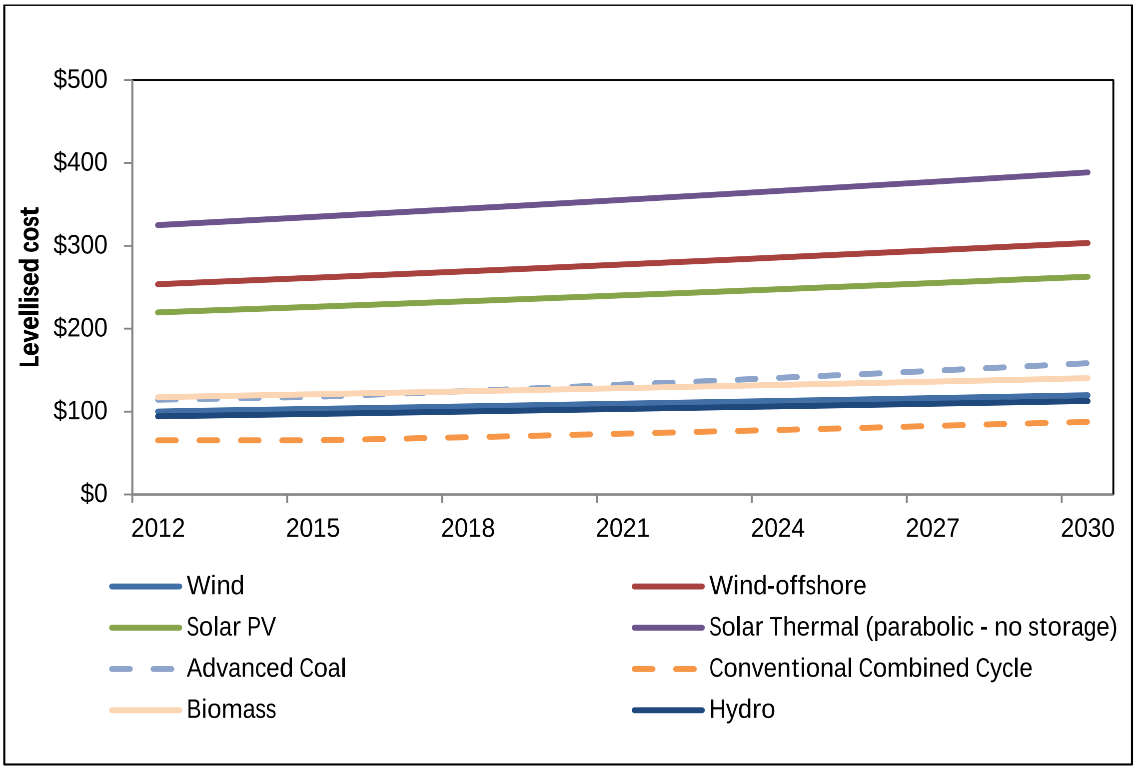
Figure 9: Optimistic scenario



Source: Carbon price from Figure 6, carbon footprint from 'Danish energy authority', levelised cost from Table 2.

Key assumptions: LCOE for conventional fuel powered plants rises at 0% (natural gas) and 3% (coal) from 2012-2015 and then at 3% (natural gas) and 5% (coal) from 2016-2030 (this would also include fuel cost inflation); LCOE for renewable powered plants reduces by 5% annual (till 2015) and then stays constant till 2030; renewable plants sell 20% of their carbon offset

Figure 10: Pessimistic scenario



Source: Carbon price from Figure 6, carbon footprint from 'Danish energy authority', levelised cost from Table 2.

Key assumptions: LCOE for conventional fuel powered plants rises at 0% (natural gas) and 2% (coal) from 2012-2015 and then at 2% (natural gas) and 2% (coal) from 2016-2030 (this would also include fuel cost inflation); LCOE for renewable powered plants constantly rise at 1% from 2012 -2030; renewable plants do not sell any carbon offset

The rationale for creating these holistic scenarios is that while the relationship between individual metrics and grid parity between fossil fuel-based and renewable-based electricity is relatively clear, rarely do these metrics move in isolation. These scenarios have allowed us to both capture the interaction between the metrics but also assess the sensitivity of the outcome of each one.

Contrasting the different scenarios highlights that almost irrespective of the nature of the carbon market there is a high likelihood that grid parity between coal and renewables can be achieved within the next 10 years or so. This is quickly discerned from the estimate of carbon price required in 2030 to ensure grid parity at that time. The analysis (see
Table 4) suggests that even at current prices, and in the base scenario, all renewable technologies considered (except for solar thermal) will achieve grid parity with coal. The encouraging aspect clearly being that this is within the timeline of a typical coal power plant's lifecycle of about 30 years. This ensures that stakeholders are forced to make a decision 'today' as opposed to deferring it in favour of investments in the next generation of coal plants. A comparison with natural gas however is more challenging. Given the projections of vast amounts of unconventional natural gas sources coming on-stream over the next 5 – 10 years, there is a serious concern that some technologies will not achieve grid parity in the foreseeable future (see Table 5). As highlighted previously, these are specifically solar and offshore wind. This is not entirely unexpected. Hydro, bio-mass and wind, arguably are the more mature of the scalable renewable technologies and therefore have lower LCOE starting points, thus making them more amenable to achieving grid parity with a lower cost fossil fuel.

Table 4: 2030 Carbon price for grid parity between renewable and fossil fuel technologies (base and optimistic scenarios)

Current assumed price: USD 7.5	Base scenario (with carbon markets)		Optimistic scenario	
	Coal	Natural Gas	Coal	Natural Gas
Wind	USD 7 - 9	USD 7 – 9	USD 7 – 9	USD 7 – 9
Wind-offshore	USD 7 – 9	USD 630 - 660	USD 7 – 9	USD 120 - 140
Solar PV	USD 7 – 9	USD 920 - 950	USD 7 – 9	USD 150 - 165
Solar Thermal (parabolic - no storage)	USD 115 - 130	USD 2000+	USD 7 – 9	USD 490 - 520
Biomass	USD 7 – 9	$920 - $950	USD 7 – 9	USD 7 – 9
Hydro	USD 7 – 9	USD 7 – 9	USD 7 – 9	USD 7 - 9

Source: Own analysis

Table 5: Indicative year of grid-parity

	Coal (indicative year of grid parity pre-2030)				Natural Gas (indicative year of grid parity pre-2030)			
	Base (with carbon)	Base (without carbon)	Optimistic	Pessimistic	Base	Base (without carbon)	Optimistic	Pessimistic
Wind	2012	2012	2012	2012	2015	2019	2015	-
Wind-offshore	2024	2025	2020	-	-	-	-	-
Solar PV	2019	2020	2017	-	-	-	-	-
Solar Thermal (parabolic - no storage)	-	-	2025	-	-	-	-	-
Biomass	2012	2012	2012	2018	-	-	2022	-
Hydro	2012	2012	2012	2012	2014	2015	2013	-

Source: Own analysis.

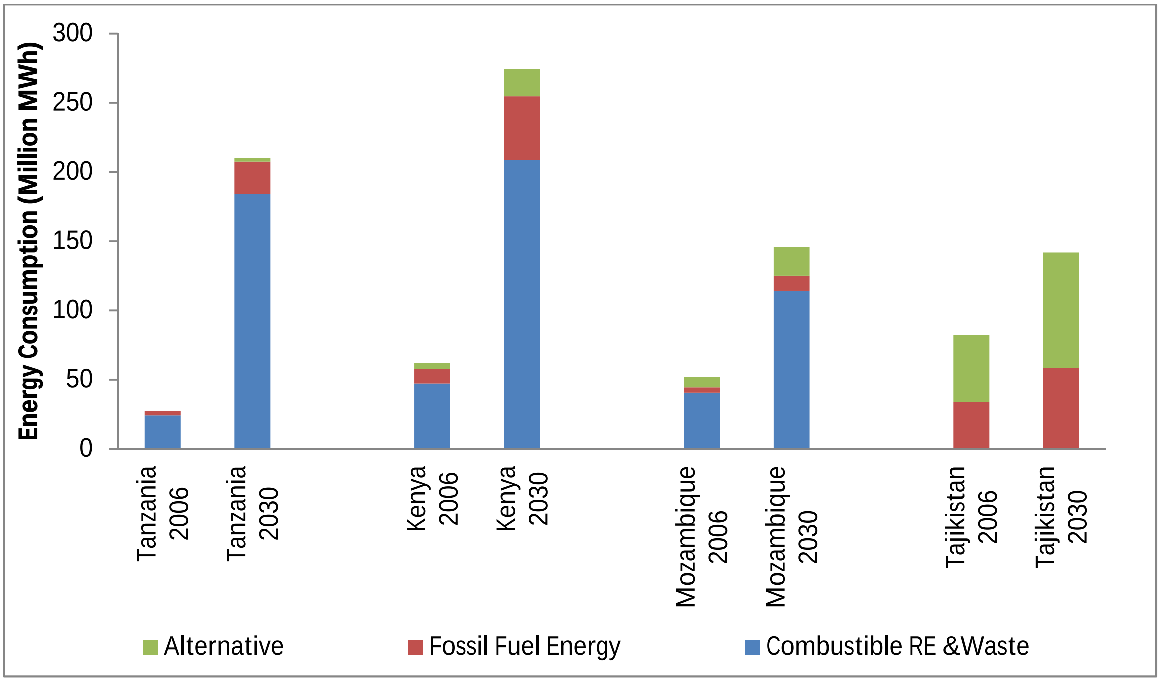
6 Conclusion

Over the course of the paper, we have explored both exogenous and internal energy challenges facing countries across the globe. Given their stage of economic development and resources at their disposal, these challenges are significantly exacerbated for LICs. The scale of these challenges therefore raises the question whether continued development along established development trajectories is sufficient to cope or if there is a need for more disruptive thinking.

While modern developmental economics suggests that the presence of modern energy is a necessary condition to enable economic growth, recent trajectories and current realities are increasingly questioning the quantum underlying this relationship. Better and cleaner technologies are more readily available today. This is allowing developing economies to redirect labour and enhance productivity (in both formal and informal sectors) thereby achieving greater output change (as a percentage) and development through the next marginal energy unit as compared to higher and middle income countries.

None of these possibilities can however detract from the fact that energy demand will continue to grow in LICs as a result of economic development and population growth. Further, while these countries currently have low energy requirements (on an aggregate and per capita basis) the increased demand for energy is in all likelihood going to be for more sophisticated forms of energy such as electricity (rather than heat). This maturing will almost certainly means that the current fuel mix, as dominated first by biomass and waste, and supplemented by fossil fuels, will not be sustainable (see Figure 11, as an illustration based on a subset of LICs).

Figure 11: Current energy mix and scale of demand from sources in 2030 assuming same mix, for selected LICs



Source: World Bank Databank, 2012

This reality of a modern energy deficit future for LICs therefore ironically also offers them the greatest opportunity to choose their energy path for the future. Broadly, there are two options (a) a fossil fuel centric trajectory, and, (b) one that has its fair share of renewable energy investments. The former scenario, one which developed countries have followed, is fraught with a number of challenges that have already been highlighted. Rising prices coupled with supply constraints could conspire to leave

LICs extremely vulnerable to market forces beyond their control. This trajectory is by definition a high-carbon approach, one that risks further complicating the climate challenges facing the globe. Interestingly, those developing countries that do have captive fossil fuel resources are increasingly asserting control over the fate of these resources through the creation of national oil companies. This trend, both amongst Middle Eastern countries as well as other developing countries may or may not provide the countries with the most effective return on investment and resources. Nevertheless this model does provide the prospect of breaking out of the resource curse model and empowering local populations with the ability to participate (individually or in partnership) in global markets for their benefit, and therefore for the short term seems like an economically lucrative approach to energy management.

The alternative approach, of investing in RE investments offers LICs the opportunity to adopt a pathway with newer and cleaner technologies. A financial analysis of competing energy technologies (particularly within the context of electricity) clearly sets out how the combination of the rising fossil fuel prices and falling costs of RE technology solutions will strengthen the argument in favour of RE technologies. These RE technologies can enhance energy and financial security by contributing to reduced national debt, improving trade balances and providing a hedge against fossil fuel price fluctuations early on in the development cycle.

This fact is demonstrated in the analysis above, which shows how over the next decade or so, should costs for fossil fuels rise, grid parity with renewables based technologies within that timeframe is a reasonable expectation. In the case that this rise is contemporaneous with the maturing of viable carbon markets we have a significantly accelerated scenario which would reduce the grid-parity timelines dramatically. While for the purposes of this argument we have placed the choice between fossil fuel and renewable technologies as exclusive, there is yet another option where countries move up the fossil fuel trajectory over the short and medium term, but then migrate towards cleaner and lower carbon technologies in the longer term. This has the advantage of using a proven development path, while waiting for newer technologies to themselves mature further. This option of grow now and clean up later, though likely, carries significant risks. First, the economic viability of newer and cleaner technologies is accelerated with higher demand. Actions are therefore required from both developed countries (for technology development) and developing countries (to adopt). Second, vulnerabilities from environmental damage (and the social cost of carbon[9]) will demand urgent action. Investing in climate friendly and cleaner technologies will therefore be more cost effective for LICs in the long term. In addition, abatement costs of converting economies from high fossil fuel to low carbon will be significant. Consider as an example India, a country that has already moved to the lower middle income status. A recent study (World Bank, 2012) suggested that for an effective carbon abatement strategy (one that reduces carbon footprint by 30% from business-as-usual (BAU) by 2030), India would need to invest as much as USD 18 billion annually between 2010 and 2030. While the current set of LICs do not share India's high growth rate or large population base, this estimate still provides a financial benchmark (without even including the environmental cost – estimated at 9% of GDP for India for any potential 'course correction' in later years).

The above analysis has also highlighted the mixed value of CERs and a viable carbon market in any trade-off between fossil fuels and renewable technologies. Currently, there is some debate about the robustness of existing regional carbon markets (for example the EU ETS). The fact that some technologies are already approaching grid parity even without the benefit of carbon markets is therefore very encouraging. To ensure that these markets do exist and flourish into the future, there has to be deliberate action on behalf of governmental and non-governmental bodies to translate learnings' over the past years into the market structure and operations. Such action will provide an incentive for all actors to participate in the markets, and ultimately result in an appropriate balance between supply and demand to drive up the price of carbon. Suitably high carbon prices are vitally important in ensuring that some of the comparisons between fossil fuel based technologies and renewables based

9 The Social Cost of Carbon (SCC) measures the full cost of an incremental unit of carbon (or greenhouse gas equivalent) emitted now, calculating the full cost of the damage it imposes over the whole of its time in the atmosphere (Price et al., 2007)

technologies are meaningful ones and can be favourably accelerated. Troublingly, recent trends suggest that this required increase in carbon prices may not be realised, as a consequence of loosening regulatory regimes. While this does not mean that renewable technologies will be condemned to being financially unviable for eternity, it does run the risk of delaying the outcome to the next generation of investments. Another risk, as seen in the past, is where the LICs are unable to participate in such market-based mechanisms irrespective of the cost of carbon. These aspects will need to be addressed more closely, such that these markets can be made more viable and be consciously developed in countries where there is large scope for dissemination and north-south participation (other than countries like India and China who are now developing technologies of their own).

There is an alternative view to this issue - where the umbrella of 'carbon markets' is representative of some financial mechanism that aids the development of RE technologies, given that in some forms they are more expensive in the short term compared to fossil fuel based technologies. The carbon costs (in 2030) needed to achieve grid parity amongst different technologies (as illustrated in Table 4) give us some sense of the scale of the financial mechanism necessary, particularly when viewed relative to the LCOEs. The format of this financial mechanism could range from grants and aids in the conventional development paradigm to subsidies and taxes as fiscal policy approaches. Consider how, in the current context RE technologies are in direct competition with fossil fuel and nuclear generation for government subsidies (both of which are supported by mature energy policies and research) (Ockwell et al., 2006; Alazraque-Cherni, 2008). A comparison of conventional energy policies and those supporting RE technologies even beyond the context of rural applications often highlights the lack of incentives for the latter, thereby raising the risks and costs of investments (Alazraque-Cherni, 2008). It is important to note that given technological maturity and costs associated with particular technologies, this issue is going to have particularly harsh implications on specific countries, for example those where the topography eliminates on-shore wind as a viable option. As a result, LICs will either default to fossil fuel based technologies, given the lower cost, or be forced into providing subsidies to renewable technologies to ensure investments are viable. The latter is highly unlikely since this places additional fiscal burden on poor nations and thus would ultimately result in the absence of material investments in the LCD pathway. It is therefore important that there is a broader rebalancing of existing producer / supplier subsidies away from fossil fuels to renewables based technologies in order to make a sustainable impact.

Our argument for LICs adopting LCD is that these countries need to provide energy to different strata of populations. Given that there are large populations living in rural areas, access to energy is faced with a dual challenge. First, ensuring energy security for communities, and second, curbing the use of traditional energy models to combat climate change. Rural access to electric energy has not advanced well in developing countries due to high investment costs associated with the extension of existing grids and the additional cost from transmission losses (a minimum of 6% per 100 km) (Glania and Rolland, n.d.). Decentralized RE solutions can provide rural electrification through affordable, reliable socially adequate, and climate friendly energy systems (Glania and Rolland, n.d.; Bhattacharyya, 2006; Kaygusuz, 2011). Importantly, a lot of the analysis above is based on cost assumptions of constructing large generation plants. While these investments will have a place in the energy portfolio of LICs, another important component will be off-grid, smaller, installations. Interestingly, a number of studies have validated the results of this analysis for smaller capacity plants, thus highlighting that this is indeed a pragmatic developmental pathway. There is a much larger point to be made about energy security as well. Halsnaes and Garg (2011) documented that industrialised countries with relative supply security and energy flexibility can use modern technologies to alleviate any capital-labour ratio restrictions and enhance overall productivity. Simultaneously energy availability in developing or emerging economies can both redirect existing household labour and enhance primarily industrial labour productivity (in both formal and informal sectors) resulting in lower energy intensity. It is therefore likely that LICs may achieve significant output change (as a percentage) and development through the next marginal energy unit as compared to middle or higher income countries.

As previously suggested, adopting this low-carbon trajectory with RE technologies will also offer other developmental benefits – most particularly employment. RE technologies often need qualified and unqualified labour in the production of key components and process inputs, much more so than those for fossil fuel technologies. Bangladesh, for instance has installed 1.2 million rural home systems that generated about 60,000 jobs in this sector (REN21, 2012). The need for energy security in LICs is therefore strongly linked to the social and economic development of millions. After many years of slow economic growth, poor political systems, technological and industrial development, the development of low-carbon technologies and the reduction of their costs can significantly improve the future of these countries. Nevertheless to achieve this, political and institutional systems, and funding mechanisms (globally and nationally) will need to be developed and strengthened.

Whilst the focus of the paper has been to understand the economic case of LCD in LICs an equally key ingredient in the conversation is the prevalent political economy within these countries. For instance, Nepal's political volatility, information opaque administrative set-up and wide-spread corruption have led to little reform in the electricity sector in the past (Nepal and Jamasb, 2011). A clear understanding of the contextual politics is an important prerequisite for adoption and implementation of low-carbon development - balancing electoral needs with poverty reduction strategies and low carbon growth. Post adoption, to ensure that the full range sustainable development benefits from RE energy technologies are realised, the adoption of cleaner development pathways requires targeted political support and guidance, improved institutional capabilities and most importantly political will in both developing and developed countries.

An example of this political will is the debate around the topic of fossil fuel subsidies. Globally about USD 775 billion is spent each year on subsiding oil, gas, and coal. IEA reports that internationally, government funding worth USD 409 billion flowed into fossil fuel industry for consumption subsidies, intended to make fuel more affordable and accessible to the consumer (reference). This has the unintended consequence of driving over-consumption and wasteful use of energy by industries and households potentially feeding back into the system as increased fuel prices. As mentioned above a majority of the LICs are low users of modern energy but will need to escalate their energy imports and increase subsidies to scale up electricity access and growth. In contrast subsidies rendered to RE technologies is only USD 66 billion (Macguire, 2012). This lack of momentum, or inability, to create less polluting energy sources whilst encouraging growth in the green economy is effectively an opportunity wasted.

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ISBN 978 1 907288 96 8
Working Paper (Print) ISSN 1759 2909
ODI Working Papers (Online) ISSN 1759 2917