TÉCNICO LISBOA

EXTENDED ABSTRACT

Road to Renewables

Comparing the future of renewable energy deployment in the context of national development levels

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Thesis to obtain the Master of Science (MSc.) Degree in

Energy Engineering and Management

(MEGE)

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June 2014

Introduction

"An environmental crisis, a development crisis, an energy crisis. They are all one." (UNWCED, 1987) The 1987 *Brundtland Report* developed by the United Nations World Commission on Environment and Development (UNWCED) brought to global attention the historically intertwined nature of energy consumption, human welfare and the environment. Consumed[1] for millennia in various forms, energy usage has rapidly increased (by a factor of 10) over the last century, and has allowed segments of humankind to develop and progress to a never before seen level of prosperity and technical advancement (Tverberg, 2012). However, this coupling of rapid advancement and energy consumption over the course of the last century has come at great costs. It has resulted in negative environmental impacts, economic shocks, and a vast divide in welfare between developed and developing countries (Bierbaum & Matson, 2013). Many of these environmental impacts, such as climate change, can be directly linked to the use of energy by humankind (IPCC, 2013). Similarly, energy insecurity and subsequent economic setbacks are a result of the dependence of humanity on fossil fuels for energy (Lovins & Lovins, 2001), whilst lack of access to energy has been attributed as one of the leading barriers to the development of nations and the elimination of poverty (Karekezi, McDade, Boardman & Kimani, 2012).

In recent decades, the negative environmental impact caused by humankind's dependence on fossil fuels for energy has resulted in an increasing push for alternatives to meet the increasing energy demand from an increasing population (Bierbaum & Matson, 2013). Similarly, global oil shocks in 1973 and 1979 which resulted in widespread economic panic and concerns over energy security led nations to commence the search for alternative sources of energy freely available within their national boundaries (Lovins & Lovins, 1983). This search for non-fossil-based energy sources due to environmental, economic and energy security reasons was reiterated in the Brundtland Report (UNWCED, 1987), with the additional concern that the lack of energy availability in developing nations due to economic inaccessibility and/or lack of natural resources was resulting in a vicious cycle of poverty for hundreds of millions of people. These three ongoing, interdependent global energy issues all echo the same demand for a solution to unsustainable fossil-based energy; namely, renewable energy.

Dependence upon imported fossil fuels impacts upon the energy security of nations, with developed nations typically concerned about the potential for political, economic and terrorist attacks via manipulation of these resources (Lovins & Lovins, 2001), whilst fluctuations in fossil fuel prices in developing countries directly impacts upon their ability to reduce poverty levels and to increase the quality of life of their citizens (Karekezi, McDade, Boardman & Kimani, 2012). Similarly, the impact of climate change, resulting from the use of non-renewable fossil fuels, will affect both developed and developing nations, albeit with a significantly greater effect on poorer developing nations with inadequate mitigation resources (The Economist, 2009). With these mutual threats from the ongoing dependence on non-renewable energy consumption, developed and

[1] Though technically energy cannot be consumed, in this report the term energy consumption means "quantity of energy applied", following the definition in ISO 50001:2011 and the future standard ISO 13273-1 Energy efficiency and renewable energy sources - Common international terminology Part 1: Energy Efficiency.

developing nations are turning towards renewables for solutions and meeting both barriers and opportunities in this search (IRENA, 2012).

The research aims to explore the opportunities for developed and developing countries to address their future energy needs through the deployment of renewable energy solutions and to establish key historical insights that can be adopted by nations on the road to increased sustainable energy consumption. This process of increased renewables deployment, much like other global changes, is often dependent upon innovative nations leading the way forward, with less-progressive countries learning from their subsequent successes and mistakes. Whilst the challenges facing such progressive nations are often dependent upon technology and natural resource availability, they are also often seen as dependent on their status as a developed or developing country. It is this development status and its potential impact on the challenges and opportunities for renewable energy deployment that is the central focus of the research.

As an engineer embedded in the International Renewable Energy Agency (henceforth referred to as 'IRENA'), the researcher is attempting to analyse the challenges and opportunities for the rapid deployment of renewable energy technologies in the end-use sectors (industry, buildings and transport) and power sectors of both developed and developing nations alike. The aim of the study is to assess the future renewables deployment opportunities in the context of developed and developing countries, and strives to:

- Successfully develop IRENA renewable energy roadmaps for a developed and developing country.
- Translate these nation-centric renewables roadmaps into results representative of developed and developing countries as a whole.
- Identify how these results can be best used to facilitate future renewable energy deployment in both developed and developing nations.

The research will attempt to test the following hypothesis:

The future deployment of renewable energy technologies will be more easily facilitated in developed nations due to greater levels of preexisting technological expertise, societal conditions and economic capabilities, and the general absence of energy poverty, which typically drives the search for access to the cheapest forms of energy (often unsustainable) to enable national development.

This hypothesis will be tested using the following research questions, which were used to guide the research:

In the context of moving towards a more sustainable energy future, what are the key challenges and opportunities for the acceleration of renewable energy deployment with respect to the level of development of a nation?

Based on present techno-economic, political, environmental and societal conditions, what level of development provides the greatest opportunity for future increases in the level of renewables in a nation's energy mix?

What lessons can be learned from nations of differing development levels concerning increased deployment of renewables?

Literature Review

The following literature review sought to provide a foundation for the research by establishing the current 'state of the art' in the fields touched upon over the course of the project, and how the outcomes of the project could affect the future directions of these fields.

Energy is "a fundamental entity of nature that is transferred between parts of a system in the production of physical change within the system and usually regarded as the capacity for doing work" (Merriam-Webster, 2014). The flow and conversion of energy has played a key role in the history of humankind, with no action having been possible without its harnessing and conversion (Smil, 2004). The current lack of widespread modern energy access in less developed countries represents one of the greatest sustainable development challenges, with human wellbeing tied directly to sustainable, reliable and enduring access to energy (Bierbaum & Matson, 2013). The apparent correlation between energy consumption and the level of development of a nation is typically based on the established relation between increased energy use and economic development. The progress of nations' level of human development and wellbeing with regards to its level of energy consumption indicates that once per capita energy usage reaches approximately 2.6 metric tonnes of crude oil equivalent per capita (110 gigajoules/capita), there are essentially no gains in national development levels with increasing energy consumption (EIA, 2005). Such a correlation suggests that whilst developing countries are currently in a state of severe energy poverty, an indefinite increase in energy consumption is not required to improve the wellbeing of a national populace. However, given the ongoing increase in global energy use due to the desire for nations to develop and alleviate national poverty levels, there is a distinct need to move away from finite energy resources to more sustainable sources of fuel if developing nations are to rise from poverty and developed nations are to maintain their current levels of prosperity with the natural global resources available (Bierbaum & Matson, 2013).

Similar to human development, climate is dependent on energy to maintain the current climatic balance that allows it to remain habitable to humanity. This energy comes directly from the sun and is retained in the climatic system by greenhouse gases (GHGs) present in the atmosphere in a process known as the 'greenhouse effect' (EPA, 2014). Whilst this process is a natural phenomenon, with the absorbed heat energy from the sun resulting in global temperatures remaining at a habitable level, recent human development has started to amplify this effect. Over the course of the last century this rapid increase in GHG levels has resulted in widespread changes to the climate, with the most cited example being that of global warming. This increasing global mean temperature is a direct result of the increasing global consumption of fossil fuels, and is projected to result in potentially catastrophic climate change if nothing is changed (IPCC, 2007). Climate change represents a global threat, with the need to de-carbonise energy consumption and to transition to more sustainable and secure methods of energy use representing a challenge that needs to be tackled from a global perspective.

Energy security is defined as "the reliable, stable and sustainable supply of energy at affordable prices and social costs" (World Economic Forum, 2014). From an economic and development perspective, energy security concerns were first raised at a global level during the oil price shocks of the 1970s, with world per-capita GDP falling from 4.9% in 1973 to 0.1% in 1975 following the Arab oil embargo, whilst GDP growth fell from 2.1% in 1979 to -0.6% in 1982 following the Iranian revolution (Van Vactor, 2007). The vulnerability of energy supply in both the developed and developing world is a result of the increasingly complex, interdependent and customised modern energy solutions, and is often overlooked when discussing the challenge of energy security (World Nuclear Association, 2014; World Economic Forum, n.d). From a fuel-supply perspective, the level of energy insecurity is highlighted by an incident in the U.S in 2001 when a single rifle bullet disrupted an oil pipeline supplying 1 million barrels per day for over 60 hours (Lovins & Lovins, 2001a). Whilst in terms of electricity supply, large-scale interdependent systems have become the norm in modern societies, and failures have threatened the energy security of millions of people in recent history. Furthermore, the historical reliance of developing nations, particularly in Africa, on fossil fuel imports and top-down centralised power generation development for growth, presents an opportunity (also for developed nations) to secure future energy supplies, and to enable growth and development through increased energy supply. More specifically, the potential for developing nations to leapfrog the traditional, centralised energy supply systems widely used in developed countries, and move to the implementation of decentralised, renewable energy systems has been highlighted by many international organisations (The Economist, 2010; Holm & Arch, 2005). Such a transition to renewables would help reduce dependence on fuel imports, improve energy access and improve overall energy security.

Renewable energy is “energy which can be obtained from natural resources that can be constantly replenished”, whilst renewable energy technologies are “technologies that use—or enable the use of—one or more renewable energy sources, including: bioenergy, geothermal energy, hydropower, ocean energy, solar energy, wind energy” (ARENA, 2014). As fossil fuels developed on a large, widespread scale, their reliability and portability in comparison to renewable energy led to the dominance of fossil fuels as a source of energy in industrialised, developed nations (Sørensen, 1991). In contrast, many developing nations continue to be dependent on renewable energy, predominantly traditional biomass for their energy needs, with biomass representing over 35% of the primary energy share of developing nations and up to 90% of developing household energy needs (REN21, 2013). Renewable energy represents a significant opportunity for countries to benefit environmentally, economically and developmentally. From the perspective of developed countries, renewable energy represents a key opportunity for reduced environmental impact and reduced energy insecurity, but it must overcome their historic dependence on fossil fuels. For developing countries, renewable energy represents an opportunity to increase energy access without the need for expensive centralised transmission and distribution infrastructure and subsequently for poverty reduction, but it must overcome fears of financial uncertainty and lack of familiarity with the available technological solutions in addition to inhibitive governmental legislation (World Future Council, 2009).

Research Design

The research was undertaken in concert with IRENA as part of their ongoing renewable energy roadmap (REmap 2030) project, and involved the completion of two country analyses: Sweden and Kenya. The

International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. In 2012 IRENA was tasked by the UN's sustainable energy for all (SE4ALL) initiative with responsibility for their third and final objective: doubling the share of renewable energy in the global energy mix by 2030 (SE4ALL, 2013). This resulted in the creation of 'REmap 2030', a Renewable Energy roadmap to double the global share of renewable energy by 2030. In determining the potential to scale up renewables, the study not only focuses on technologies, but also on the availability of financing, political will, skills, and the role of planning (IRENA, 2014). The project provides renewable energy deployment options based on a bottom-up analysis of official national sources.

The research followed the Global Tracking Framework (World Bank et al., 2013) approach to assessing the national level of RE penetration, focusing on the Total Final Energy Consumption (TFEC)[2] in the three energy end-use sectors in society: industry, buildings, and transport. In determining the RE share in national TFEC, it was estimated as the sum of all renewable energy use by all energy sources (e.g. biomass, solar thermal etc.) and the share of RE in district heat and electricity consumption (IRENA, 2014b). However, given the typically unsustainable nature of traditional biomass resources, energy consumption sourced from traditional biomass was considered to be equivalent to fossil fuels (i.e. non-renewable) for the purpose of the REmap country analyses. In completing the research the following steps were undertaken:

- Data collection;
  - The present energy situation (base year 2010) in the country, and;
  - The market potential for renewable energy: replacements, expansion and retrofits.
- Reference Case;
  - The development of national energy consumption trends through 2030 based on the current policies and policies under consideration in the country, representing 'business as usual'.
- REmap Options;
  - The potential for the deployment of an increased share of renewables in the final energy mix.

Upon completion of the REmap country assessments for Sweden and Kenya, the results were then used as the basis for the analysis of the ability of developed and developing countries to transition towards a substantially increased share of renewable energy in their final energy mix. The results for Sweden were used to represent developed nations, with the Kenya results representative of developing nations. A direct comparison of the respective potential of the two countries to increase their RE shares, levels of RE consumption and subsequent costs of substitution was undertaken using these results. The subsequent analysis addressed the potential social, environmental and political issues and challenges facing the deployment of renewables in the two countries. These challenges were then expanded to form an indicative assessment of the potential for RE in

[2] TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for industry and building sectors) as well as electricity and district heat. It excludes non-energy use, which is the use of energy carriers as feedstocks to produce chemicals and polymers.

developed and developing countries, with the analysis of the REmap results being used to address the research hypothesis and research questions.

REmap provided a unique method for engaging governments through the objective use of national data and governmental feedback to provide options for a renewable transition rather than fixed scenarios. However, the methodological process outlined gave rise to two key limitations that, as with all data analyses, resulted in the need for careful, objective consideration of the process findings that result from the analysis. These two limitations pertained to:

- Data availability; depending on the country being analysed, the energy consumption data available for analysis could be quite limited, requiring substantial extrapolation from historical trends.
- Simplified analysis approach; the substitution of non-renewable technologies with RE solutions did not take into account the inter-linkages and interdependencies of different technologies within a national energy system, and the subsequent costs of infrastructure development for this new RE capacity.

Furthermore, whilst Sweden and Kenya were comparatively similar, every country is unique in its energy consumption trends, resource availability and social, environmental and political trends. As such, it was difficult to condense the RE potential of all developed and all developing countries down into two representative cases, as was done in this research.

Results

Developed Nation – Sweden

With a total final energy consumption (TFEC) of approximately 1.4 exajoules (EJ) in 2010, Swedish energy consumption is dominated by the industry and building sectors, representing 37% and 39% of TFEC respectively, with the transport sector making up the final 24% (IEA, 2012). Capitalising upon substantial renewable energy resources, the share of renewables in the 2010 energy mix of Sweden is the largest within the European Union (EU) and the second largest in Europe. Representing almost 48% of their TFEC, renewables consumption is centred in the industry and buildings sectors, with less than 7% of transport energy use being derived from renewable sources. Whilst the renewable energy resource potential of Sweden is significant, the current level of renewable energy use in the country has resulted in significant exploitation of the preexisting, economically feasible biomass and hydropower resources. Although there still remains approximately ≥200 PJ/year of economically feasible biomass resources and another 25 PJ/year of economically feasible hydropower to be harnessed, if Sweden is to work towards a 2030 energy supply with a greater renewables share, then additional renewable resources that are currently underexploited will need to be further developed. In addition to its substantial potential for economically feasible renewable resource development, Sweden is host to a political mindset that is historically ambitious in terms of renewable energy targets and reform, reflected in its drive for 50% renewables in TFEC by 2020 and emissions free energy use by 2050 (Swedish Government, 2010).

In order to assess the potential to which the future Swedish energy mix could contribute to the REmap 2030 objective of the global doubling of the renewables share by 2030, an understanding of the likely appearance of the Swedish energy mix landscape in 2030 under business as usual (BaU) development conditions was completed. The Reference Case was based on Swedish Energy Agency (SEA, 2013) projections, resulting in an increase in the total RE share in TFEC by 4.5%, from 47.7% in 2010 through 52.2% in 2020, before plateauing between 2020 and 2030 and seeing a smaller increase of 1.2%, to an RE share of 53.4% (with the RE share in the transport sector failing to meet the Swedish target of 10% by 2030). With a continued high share of non-renewable energy use projected for 2030 under BaU, it was found that there was significant potential for the implementation of higher shares of renewable energy in Sweden to substitute these non-renewable energy sources. This potential, represented by 'REmap Options', found three key opportunities for increased renewables development in Sweden:

- Biomass;
- District heating, and;
- Electrification.

When these opportunities for increased renewables deployment were applied in four REmap Options cases, an increase of RE share in Swedish TFEC to between 70% and 75% was found to be possible at an average local cost of non-renewable energy substitution of 1 to -9 USD per GJ of energy substituted. The higher substitution costs were a result of transitioning towards a biofuel-based transport sector, whilst the lower costs related to the use of biomass-based district heating in the place of electric and gas heating.

Developing Nation – Kenya

With a total final energy consumption (TFEC) of approximately 0.54 exajoules (EJ) in 2010, Kenyan energy consumption is dominated by the buildings sector, representing 78% of TFEC, with the transport sector representing 13% of TFEC and industry making up the final 9% (IEA, 2012). Kenya is endowed with substantial renewable energy resources, especially geothermal, but the unsustainable exploitation of traditional biomass for 70% of its energy consumption, all of which is consumed in the buildings sector, and the dominance of oil in the industry and transport sectors, results in a rather low share of renewables in the 2010 energy mix. Representing 2.8% of TFEC, renewables consumption (excluding traditional biomass) is currently limited to the power sector where hydropower and geothermal represents 65% of all electricity generation (IEA, 2012). Whilst the renewable resource potential of Kenya is substantial, much of the available renewable sources are currently underexploited. This is predominantly due to financial and technological restrictions, in addition to a lack of understanding of the exact resource potential resulting from a lack of detailed case studies. In contrast, widespread, unsustainable dependence on traditional biomass at an individual level represents a significant hurdle to be overcome, both socially and technically, for Kenya to transition to a higher share of renewables in the buildings sector. In addition to substantial resource potential for the deployment of renewables, Kenya has developed a long-term plan for the economic development of the country. This plan, known as 'Vision 2030', strives to make Kenya a "middle-income country providing a high quality life to all its citizens by the year 2030" (Government of Kenya, 2007). As part of this plan, rapid economic growth is linked to substantial growth in the power sector (at close to 15% per year) through to 2030, but little attention is given to non-electricity consumption (Government of Kenya, 2014).

Future Kenyan energy consumption under BaU conditions through to 2030 was based on the national economic vision for development 'Vision 2030' (Government of Kenya, 2007) which expounded the need to develop energy infrastructure to facilitate growth (projected at 10% GDP growth each year from 2010 to 2030). However, a second Reference Case was also developed to provide a comparison of future Kenyan energy use in the event that economic development did not proceed as is expected through to 2030. Given the lack of focus on the development of end-use sector energy consumption to 2030 the analysis applied an indicator-based approach, with individual indicators developed for different sectors. These indicators were then combined with the estimated growth in gross-domestic product (GDP) to determine TFEC for the 'high' and 'low' Reference Case for Kenya in 2030. From these reference cases, REmap Options were developed, with the main focus on a transition from traditional biomass consumption to more sustainable utilisation of biomass resources. Focus on modern biomass deployment was a result of the continued low penetration of electricity in TFEC, which was estimated to only increase from 4.2% of TFEC in 2010 to between 9.4% and 15.8% in 2030, effectively limiting the impact of increased renewables in the power sector. The two REmap Options cases indicated that an RE share of between 55% and 65% could be reached at an average local cost of fossil fuel substitution of 2.8 to 4.4 USD/GJ, up from the approximately 30% RE share in 2030 Kenya under business as usual conditions. The positive cost of substitution was a result of the high cost of replacing essentially free traditional biomass use for cooking and water heating, with sustainably sourced biomass using clean cook-stoves.

Discussion

The completion of the IRENA REmap country analyses provided an apt starting point for the discussion of the separate challenges and opportunities facing developed and developing countries for the acceleration of renewable energy deployment. The two case studies, Sweden and Kenya, were used as representative analyses of all developed and developing nations respectively. However, given the sheer differences in individual national circumstances, the results of the two countries were compared directly, before being generalised in an attempt to represent developed and developing countries as a whole. The comparison of future RE deployment potential in Sweden and Kenya, and subsequently in developed and developing countries, attempts to address the research questions outlined at the beginning of the research, in order to test the initial hypothesis.

The renewable energy roadmap options (REmap Options) for Sweden highlighted the societal, technological and economic potential for Sweden to substitute fossil fuel use for renewables. As a highly developed society, not only was public awareness of and interest in the increased deployment of sustainable energy technologies well established, but the technology required to substitute fossil fuels was also readily available. This technical expertise and resource availability (modern biomass and renewable resources for power generation) provides the opportunity for Sweden to increase its renewable energy share from 47.7% in 2010 to 70%-74% by 2030 at an average cost of -6 to -9 USD/GJ. That is, Sweden has multiple potential pathways to deploy significantly higher levels of renewables than under Reference Case conditions at a negative cost of substitution, despite excluding externalities. This suggests that a future transition from fossil fuels to renewables in Sweden is not only possible, but economically, socially and technically viable. In comparison, the REmap Options for Kenya highlighted a society with a low level of development and high levels of energy poverty. This resulted in limited options available for the substitution of current (and future) fossil fuel consumption by renewables. The main feasible options for increased RE in 2030 were in the power sector, due to significant renewable resources available for electricity production, through the improvement of existing traditional biomass consumption i.e. the use of more efficient cook-stoves, and obtaining biomass from sustainable sources. The deployment of these options provides the opportunity for Kenya to increase its RE share from 2.7% in 2010 to between 41% and 46% by 2030 at an average governmental cost of -3 to -4 USD/GJ. However, the individual cost of such a technological transition is close to 11 USD/GJ at a household level. In a developing country such as Kenya, this high cost represents a significant hurdle to individual adoption of sustainable energy consumption practices, despite the long-term health and variable cost benefits. This suggests the need for external intervention from those with technological expertise and an understanding of such a situation.

From the perspective of developed nations in general, the main challenge to RE deployment relates to the high level of infrastructure development, which has resulted in an extremely interconnected and centralised energy system (Lovins & Lovins, 2001). These centralised systems have attempted to capitalise on economies of scale, resulting in the concentration of electricity production in a small number of large facilities e.g. 38% of Sweden's electricity generation in 10 nuclear facilities. This concentration of production in large-scale facilities requires high levels of capital expenditure, resulting in the 'lock-in' of investment in generating capacity for the lifetime of the non-renewable power plant (20-60 years), which in turn results in countries' reluctance to substitute these investments with renewable technology before they have made a profitable return on these sunk costs (IRENA, 2014d; Brown et al., 2008). In addition to this capacity lock-in, many governments in developed nations appear quite conservative towards renewable energy target commitments, in spite of generally high levels of public acceptance for renewables in developed countries (Devine-Wright, 2008). One such example is Sweden, where renewable electricity 2020 targets were already reached in 2011, with no implementation of governmental plans for new 2020 targets and a lack of concrete targets through to 2030. This suggests that although the transition to increased renewables deployment in developed countries is technologically and socially feasible, it will likely be driven by individuals and the private sector rather than by a centralised governmental approach.

In developing countries, the main challenge to be addressed is the growing energy demand through to 2030. This results from the combination of future population growth and the aim of many developing nations to reduce poverty through economic and per capita energy consumption growth (UNIDO, 2014). This yet non-existent energy demand requires increased deployment of fuels and power generation capacity, and presents a 'clean slate' opportunity for developing countries to increase their share of renewables. Such an opportunity, if exploited, would allow developing countries to leapfrog the centralised, large-scale, fossil-based energy models of developed countries and transition directly to a renewables based energy mix, whilst avoiding the capacity lock-in issue faced by renewable deployment in many developed nations (CSE, 2014).

Implications and Conclusions

The research into the feasibility of the future deployment of renewables in developed and developing countries has raised significant implications for global sustainability and resource availability. Future economic and population growth in the developing world is projected to continue well into the future as developing nations strive to rise from poverty and provide a suitable level of welfare for their citizens. However, given this desire for the elimination of poverty, and the trend towards economic development and growth to achieve this, there will be an increasing demand for energy in the future that needs to be met. In order to minimise the environmental impact of such growth and development, it is imperative that there is a global transition towards renewables. Such a transition requires the need for developed and developing nations alike to work together in a global context, with the need to overcome nationalism and country borders vital for the most effective implementation of renewable projects.

The completion of renewable energy roadmaps on behalf of the International Renewable Energy Agency (IRENA) provided the researcher new insight into the importance of energy and its integral use in all parts of society, not just in the power sector. The comparison of the two country analyses, Sweden and Kenya, provided a glimpse into the similarities and disparities of energy use in developed and developing countries, and the potential for such nations to transition to a future of energy use based around renewables. However, completion of the research also raised the need for the following future work to verify these results:

- Compare and contrast the validity of the generalised conclusions for developed and developing nations, by completing and comparing additional REmap country analyses and comparing the results with those outlined in this report;
- Upon validation of the conclusions, some of the proposed technological substitutions of fossil fuels for renewables should be implemented in partnership with the case-study countries. This would allow for the research to progress from a desktop study to a trial-run at a national level implementation, which could be used as an example for developed and developing countries alike.

Whilst it is a simple enough matter for the researcher to make recommendations based on the completion of desktop studies, it is much harder to implement them in practice. If the future global energy mix is to see a meaningful level of renewables deployment, there is much need for countries to work together and learn from each other. This transition to renewables is a vital and likely inevitable one, as is made apparent by the financial gains from fossil fuel substitution by renewables outlined in the research. However, it is just a matter of how long national development and the subsequent rise from poverty will be hampered by dependence on unsustainable energy consumption, how much (potentially irrevocable) damage will be done to the global environment, and how much national energy security and individual welfare will come to be affected by this in the meantime. In short, the future of global energy consumption is merely a question of whether we will have development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

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